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IDAUP Coordinator Prof. Roberto Di Giulio

A multi-criteria methodology for the integration of Risk Assessment into Spatial Planning as a basis for territorial resilience

The case of Seismic Risk

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(Area 08 – SSD: ICAR/20 Urban and Regional Planning)

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Thesis Title:

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Abstract (English)

Rapid urban development and continuous demands for space have increased the pressure on the territory. The need for this “usable” space, no matter the purpose, leads to an excess of capacities of existing areas and the creation of new areas, both significantly increasing the level of exposure to natural disasters. Statistics show that within a period of almost two decades from 1994 to 2013, 218 million people were affected by natural disasters annually (CRED, 2015). In the situation where the demand for growth is accompanied by an increasing potentiality of damages in economic, social, environmental or cultural terms, disaster risk management (DRM) is having an important focus in terms of research.

The way communities and urban systems react to a natural distress is tightly related to the economic and technological development as well as data availability. Developed countries have the capacities to consider mitigation strategies in pre-event situations, which is not always feasible for developing and poor countries. Also, as emphasized by (Gaillard & Mercer, 2012), the issue is related to the fact that disasters affect those who are marginalized and have partial or no access to resources and means of protection. Such paradigm imposes the need to develop preventive strategies focusing on the community, which is directly affected by aftermath of these natural events.

The analysis of natural disasters and their impact on the society and the built environment is complex and requires an integration of multi-disciplinary information from social to exact sciences. The main issue that hinders the entire process is mainly related to the effectiveness of transmitting such an information between different stakeholders such as experts, responsible local and national authorities and the community itself. This process is even more difficult in the conditions where there is a lack of information, appropriate tools and also the lack of risk perception by the community, especially in the cases of disasters having a relatively large return period such as earthquakes.

The purpose of this research is the analysis of a possible way to integrate disaster risk information within planning instruments aiming towards an inclusive disaster risk reduction (DRR) process through the proposal of a risk assessment methodology at a local scale for the case of seismic events. The analysis is carried out through the proposal of a hierarchic system containing several parameters that characterize firstly the hazard itself and secondly, the built environment in terms of exposure and vulnerability by a combination of a multi-scale information (building and local scale). The selection of relevant parameters, their value, the relationship to one another and their contribution will be given based on a thorough

literature research, site visits, questionnaires and experts opinions. The results will be given in the form of a visual spatial information using mapping processes.

The main objective is that the proposed methodology will serve as a preliminary tool for several decision-making processes in terms of strategic risk reduction measures, policies, prioritization, fund allocation etc. The methodology is also aimed to serve as an important node that connects the community, the experts and responsible authorities with one another towards an inclusive disaster risk reduction approach.

Abstract (Italian)

Il rapido sviluppo urbano e le continue richieste di spazio hanno aumentato la pressione sul territorio. La necessità per questo spazio "utilizzabile", indipendentemente dallo scopo, porta ad un eccesso di capacità delle aree esistenti e alla creazione di nuove aree, in entrambi casi aumentando notevolmente il livello di esposizione ai disastri naturali. Le statistiche mostrano che in un periodo di quasi due decenni, dal 1994 al 2013, 218 milioni di persone sono state colpite ogni anno da disastri naturali (CRED, 2015). Nella situazione in cui la richiesta di crescente utilizzo del terreno è accompagnata da una crescente potenzialità dei danni in termini economici, sociali, ambientali o culturali, la gestione del rischio dei disastri sta avendo un ruolo sempre più importante in termini di ricerca.

Il modo in cui le comunità e i sistemi urbani reagiscono ad un evento naturale è strettamente correlato allo sviluppo economico e tecnologico, nonché alla disponibilità dei dati. I paesi sviluppati hanno la capacità di prendere in considerazione strategie di mitigazione in situazioni pre-evento, il che non è sempre fattibile nei Paesi in via di sviluppo e in quelli poveri. Inoltre, come sottolineato da (Gaillard & Mercer, 2012), la questione è legata al fatto che i disastri colpiscono la parte di comunità emarginata e che ha accesso parziale o nullo alle risorse e ai mezzi di protezione. Tale paradigma impone la necessità di sviluppare strategie preventive incentrate sulla comunità, che è direttamente colpita dalle conseguenze di questi eventi naturali.

L'analisi dei disastri naturali e del loro impatto sulla società e sull'ambiente urbano è complessa e richiede un'integrazione di informazioni multidisciplinari dalle scienze sociali a quelle esatte. Il problema principale che ostacola l'intero processo è principalmente legato all'efficacia della trasmissione di tali informazioni tra le diverse parti interessate come esperti, autorità locali e nazionali che hanno responsabilità in tal senso e la comunità stessa. Questo processo è ancora più difficile nelle condizioni in cui mancano informazioni, strumenti adeguati e anche la mancanza di percezione del rischio da parte della comunità, soprattutto nei casi di catastrofi con un periodo di ritorno relativamente lungo come i terremoti.

Lo scopo di questa ricerca è l'analisi della possibilità di integrare le informazioni sul rischio di disastro all'interno degli strumenti di pianificazione che mirano a un processo inclusivo di riduzione del rischio, attraverso la proposta di una metodologia di valutazione del rischio stesso a scala locale per il caso di eventi sismici. L'analisi viene condotta attraverso la proposta di un sistema gerarchico contenente diversi parametri che caratterizzano in primo

luogo l’azzardo stesso e in secondo luogo l'ambiente urbano in termini di esposizione e vulnerabilità mediante una combinazione di informazioni multiscala (edificio e scala locale). La selezione dei parametri rilevanti, il loro valore, la relazione tra loro e il loro contributo, saranno analizzati sulla base di un'approfondita ricerca bibliografica, visite in situ, questionari e opinioni di esperti. I risultati saranno forniti sotto forma di informazioni spaziali visive utilizzando processi di mappatura.

L'obiettivo principale è che la metodologia proposta serva da strumento preliminare per diversi processi decisionali in termini di misure strategiche di riduzione del rischio, normative, definizione delle priorità, allocazione dei fondi, ecc. Lo scopo ulteriore della ricerca è anche quello che la metodologia proposta serva da nodo di collegamento tra la comunità, gli esperti e le autorità responsabili tra loro verso un approccio inclusivo alla riduzione del rischio delle catastrofi.

Acknowledgements

Remembering the initial steps as an undergraduate student, it always makes me feel nostalgic of all the experiences throughout this amazing and challenging journey. Initially I would like to thank my supervisor prof. Luljeta Bozo. Nothing would have been possible without her help, advices and the faith shown in me since my early days as an assistant lecturer. A huge thank you goes to prof. Besnik Aliaj for his continuous support and motivation to keep working on this field of research.

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Sincere thanks to Prof. Josè Matos and Elisabete who helped me during my study period in Portugal, to Prof. Ylber Muceku and Prof. Kemal Edip for their valuable feedback and to Prof. Luca Emanueli. I would like to extend my gratitude to prof. Llazar Kumaraku and prof. Skënder Luarasi for their suggestions during the entire research and to all of the colleagues of XXXV cycle with whom I shared this journey.

This work is entirely dedicated to my family, my wonderful parents and sister, hoping that I've made them proud and worth of all the sacrifices they made for me since I was a child. Every achievement and every step taken is a reflection of all the support and love you always provided me.

Time won't stop flowing; take the chance, create memories and be a better version of yourself.

Forever grateful

E.

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1 Introduction

"No research is ever quite complete. It is the glory of a good bit of work that it opens the way for something still better, and this repeatedly leads to its own eclipse"

-Mervin Gordon

The introductory chapter of this dissertation has the aim of providing an overview of the motivation behind this research, the identified problem, the purpose of the study together with the primary and secondary questions that would constitute it. The methodological aspects and the instruments used to achieve the final goal are described in general with the aim of further detailing them throughout the following sections of the dissertation. Another important part is that of emphasizing the research perspective and of course its limitations, giving the strongest points, but also trying to put forward issues that could be later improved in the future. An overview of the dissertation structure in terms of chapters is given in the end in the "Chapters Outline" section with the aim of giving a brief introduction of each of the chapters that constitute the research.

1.1 Motivation and Problem Statement

One of the greatest challenges of human society over the years has always been adapting and living in the constant presence of natural hazards. A detailed study by (Ritchie & Roser, 2014) showed that only in the last decade natural disasters have affected a total of 186.5 million of people (injured, affected and homeless), with an average of 47000 fatalities, making such disasters responsible for 0.1% of deaths. The following charts show the variability in these numbers, which clearly reflects that even though there is a decreasing tendency in the number of the people that are affected and the total number of fatalities the unpredictability of such events can cause a considerable change in the pattern.

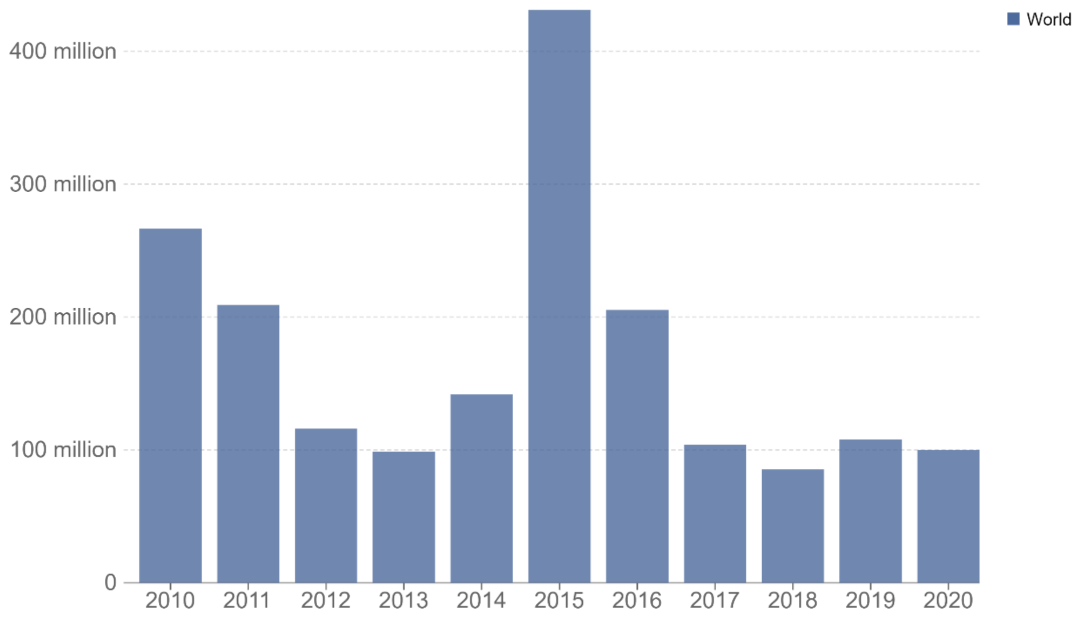


Figure 1.1 Number of total people affected by natural disasters (Our World in Data based on EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be D. Guha-Sapir)

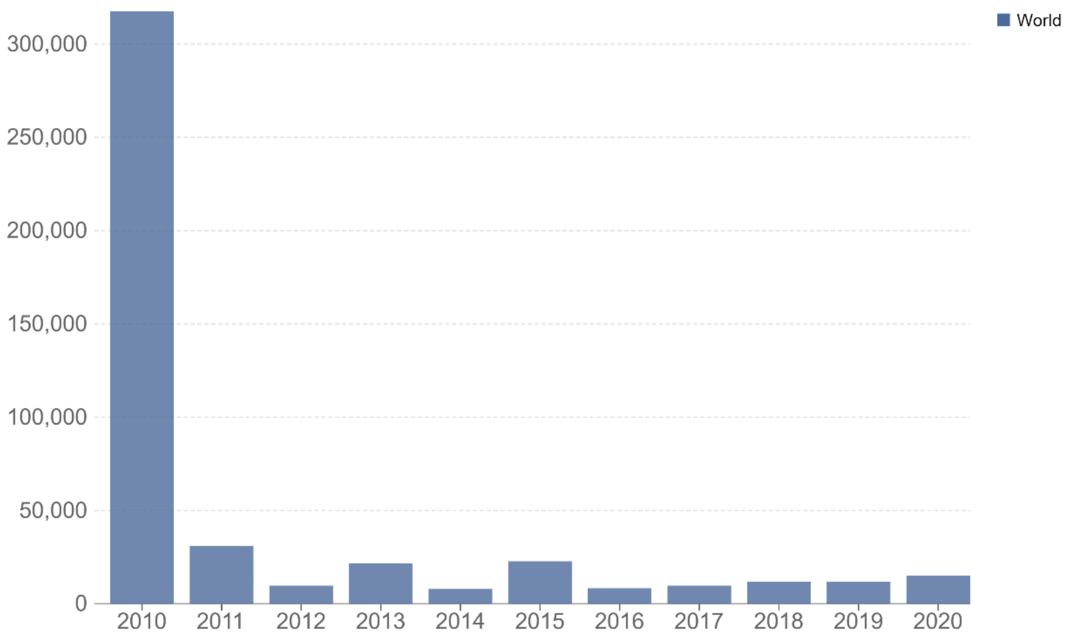


Figure 1.2 Number of fatalities from natural disasters (Our World in Data based on EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be(D. Guha-Sapir)

The visualization in the Figure 1.3 shows that historically, flooding and droughts were the main cause for disasters. In the last decades the losses from such events have decreased considerably, with earthquakes being the main event causing losses and fatalities due to the low-frequency but high-impact nature. This reflects effective mitigation measures and appropriate adaptive capacities due to the ability to predict such hazards, which is not the same in the case of earthquakes.

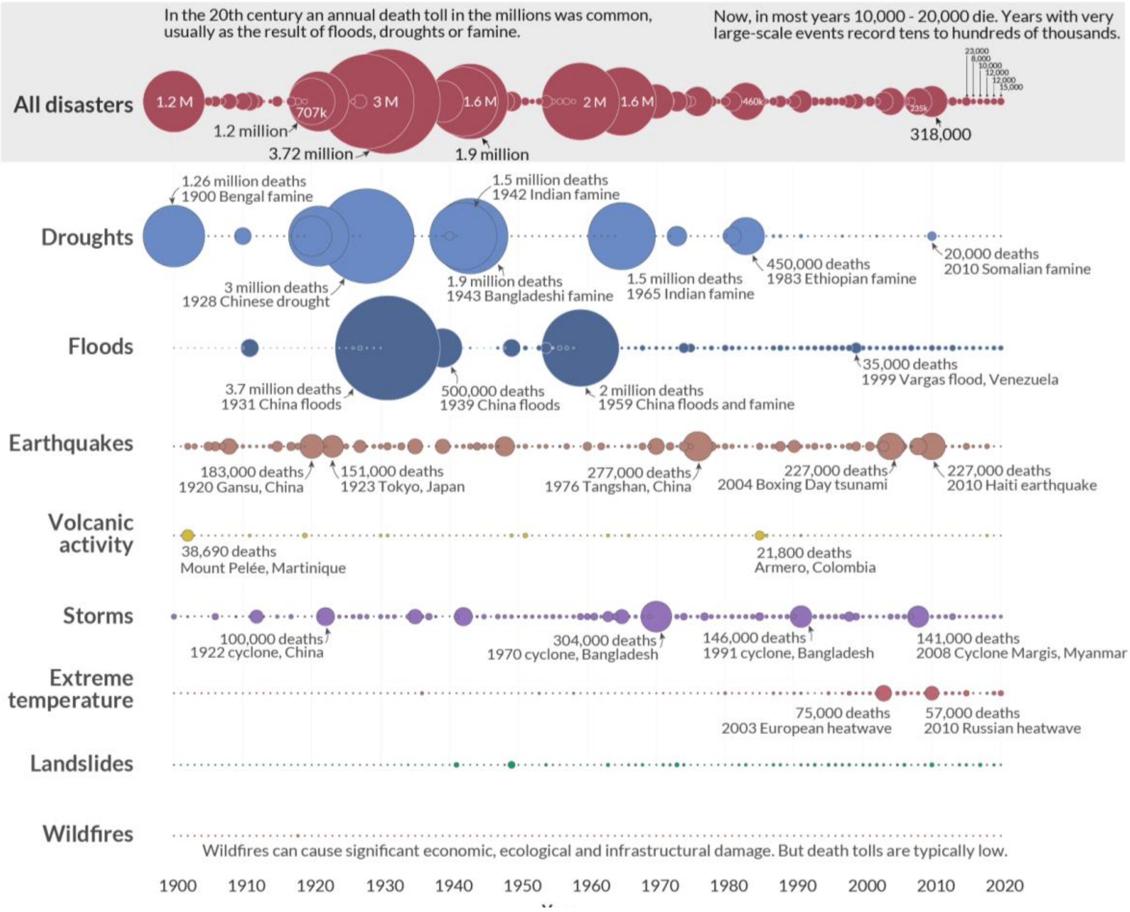


Figure 1.3 Global fatalities from disasters over more than a century (EM-DAT, CRED/ UCLouvain, Brussels, Belgium- www.emdat.be D. Guha- Sapir)

The following chart reflects an increasing trend of the impact (expressed in number of fatalities) earthquakes have had during the last two decades in comparison to other natural disasters.

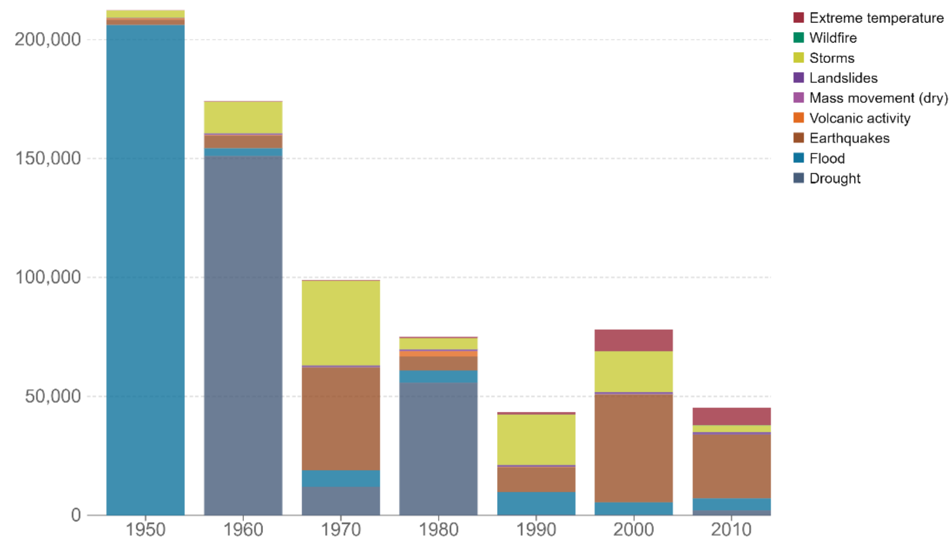


Figure 1.4 Number of fatalities from natural disasters in a global scale (Our World in Data based on EM-DAT, CRED / UCLouvain, Brussels, Belgium – D. Guha-Sapir)

The historical data show that losses to natural hazards tend to be centered in low-to-middle income countries that lack of appropriate infrastructure to cope with such events (Ritchie & Roser, 2014). One of the latest events that reflects such situation is the earthquake that struck Albania on 26 November 2019 at 02:54:12 (UTC) with a magnitude Mw 6.4 and an epicenter close to the Adriatic coastline 30 km west of Tirana and a focal depth of 22 km due to the thrust faulting near the convergent boundary of the Africa and Eurasian plates (USGS, 2019). The event caused 51 fatalities, injured around 3000 people, left up to 14,000 people homeless and caused serious damages to over two thousand buildings of different typologies (Charleson et al., 2020). Considered as the strongest earthquake to hit Albania in 40 years after the Mw 6.9 Montenegro earthquake of 1979 which was highly felt in the northwestern part of the country near to the epicenter. In engineering terms, taking into account the magnitude of the event, it is considered as an earthquake which even though may be classified as strong, was definitely not in the levels of what is known as the *design earthquake* used to design seismic-resistant structures. Nevertheless, the damages and the aftermath were quite severe.

The aforementioned summary in terms of statistical data and events, puts forward two key issues related to natural hazards and the behaviour of humans and systems; that of *exposure* and *vulnerability*. Sciences like seismology, meteorology, geology or hydrology just to mention a few, analyze hazardous events in probabilistic terms to try and predict as correctly as possible their nature, occurrence, magnitude, or any additional parameter. In other words, they *characterize the hazard,* which may be defined as:

> "*A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental change.*" (UNISDR, 2009, p.17)

Therefore, the hazard gives the source of the threat, which could either be natural or man-made, but for the purpose of this dissertation, only the former type will be taken in consideration. In the situation where a hazard strikes a certain area several stakeholders like politicians, economists, planners and the entire population living in these built environments, are not interested in its magnitude or technical parameters, but rather on the impact and *consequences* of the event.

This is where the term *disaster* is introduced, which must be said is often confused with the *hazard* itself being sometimes quite misleading. Disaster may be defined as:

> *"A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impact, which exceeds the ability of the affected community or society to cope using its own resources." (UNISDR, 2009, p.9)*

The disaster represents the impact and the consequences and to talk about consequences in addition to the hazard, the exposure and vulnerability introduced above must be analyzed and combined. Both exposure and vulnerability are components whose aim is that of answering the following questions:

Which are the affected elements?

What levels of damages can potentially happen in these affected elements?

Would these levels of damages lead to a disaster or to a slight disruption?

How long would it take to recover?

To answer these questions there is a need to study not only the characteristics of the source, but also the characteristics of the built environment and all of its constituting elements. Not every hazard can lead to a disaster, the combination of the hazard with specific poor conditions of the built environment leads to disasters.

There are two broad categories of disasters based on the apparent origin: technological and natural. The former is caused by the failure of manmade systems (Weisaeth, 1994) while the latter is caused by major natural events like earthquakes, hurricanes, flooding etc. The analysis of the disasters regardless of their origin is a function of the relationship between human systems and the environment, so it is fundamental to understand that while the origin of the event is *natural* the origin of the disasters is anthropogenic. Hazardous events of a *natural* origin have historically threatened human lives and will certainly continue to do so, as they are inevitable and eventually cannot be stopped. What has changed and will continue to change is the conflicting relationship humans have with the environment, constantly consuming and adapting it to fulfill increasing spatial needs, therefore creating a dynamic system made of many components that have a complex relationship with each other that would therefore be affected by these events.

The toppling of Kobe- Osaka highway (Fig. 1.5) due to the Kobe earthquake of 1995, for instance, besides the obvious structural damage and local effects, brought also serious problems in long term due to the hindering of accessibility and mobility.

Figure 1.5 Toppling of Kobe- Osaka highway due to the Kobe Earthquake of 1995 (japantimes.co.jp)

Such an example shows how complex dynamic urban systems are impacted at a large scale due to a local impact. In the situation of the 21st century where there has been an exponential increase in population and needs and where many developing countries are making efforts to improve their resources, following this principle is easier said than done. This typical high request of usage leads in the first place, a consumption behind the capacities of the built environment and secondly leads to the exploiting of new areas that in many occasions are prone to several natural disasters. The process tends to lead to an increasing *risk* of these systems towards natural hazards if this development is not appropriate since it would increase its *vulnerability* making the entire system and its components highly susceptible to damaging effects. The Durrës earthquake mentioned in the beginning is a reflection of this situation, where the consequences were much higher due to increasing levels of vulnerability of the affected area. There are a lot of analyzed factors that brought such high levels of vulnerability; the quality of construction materials, structural design, the lack of a proper assessment of soil conditions and informal development are just some of these factors.

The approach towards these events and the ability of the system to absorb the stresses from the events in the past was focused in the phase of emergency response and the eventual reconstruction phase, while nowadays there is a shifting paradigm toward prevention strategies before the disaster strike (Sutanta et al., 2010). Being able to prevent the damages from an event before it even happens implies the need to try and predict the damages that this event might cause in a certain area, so it might be considered as an ex-ante analysis. This analysis is widely known as *risk analysis and assessment*. The entire process of the risk assessment and eventually the reduction of this risk involves many disciplines and is seen from different perspectives, as such there is an essential need for an integrated approach and a cooperation between different actors in different levels.

Based on the large number of studies on disaster-related issues, (Gaillard & Mercer, 2012) emphasize the emerging of two major paradigms; hazard and vulnerability paradigm. The former asserts that disasters occur due to the insufficient perception of risk of the affected people which consequently fail to adapt and adjust to reduce such disasters, therefore can be considered as a generalized approach. On the other hand, the latter paradigm asserts that disasters affect mainly those who are marginalized and lack access to resources and means of protection. Within the second paradigm it is believed and supported that Disaster Risk Reduction should be inclusive in terms of:

- the form of knowledge (scientific and local knowledge)
- combination of top-down and bottom-up actions
- collaboration and operation of large array of stakeholders

The lack of this inclusive process together with increasing vulnerabilization levels is believed to be one of the main reasons of why disasters are on rise worldwide.

The community affected by a disaster is dependent on the interrelated urban systems. At an urban scale, resilience (whose concept will be further defined in the following chapters) depends on the ability to maintain essential assets and ensuring access to services and functions. The following scheme gives the characteristics of resilient cities:

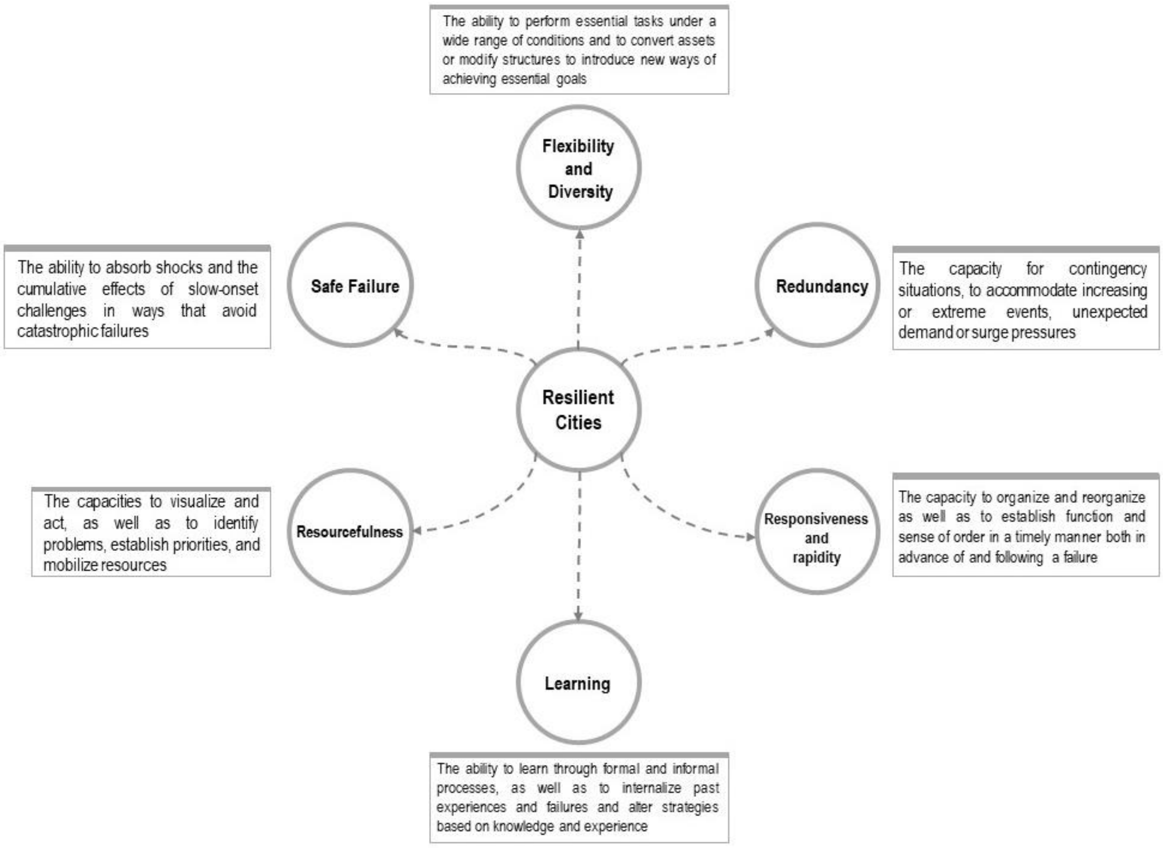


Figure 1.6 The characteristics of resilient cities (adapted from Dickson et al., 2012)

Spatial and urban planning is one of the disciplines that is involved in the matters of risk assessment since its function is to regulate utilization of land, therefore can be considered as an important link in the entire process and can be very useful to reduce the exposure and vulnerability of the entire components affected by the hazard. It is also believed that planning instruments represent a fundamental link in bridging the aforementioned gaps that hinder an inclusive process. As stated by (Suri, Johnson, Lipietz & Brennan, 2020) to be able to create resilient cities planners need to approach disaster risk reduction (DRR) as an issue at the center of a good urban development, whose integration however is often limited.

1.2 Purpose of the study

The previous section reflects a number of issues and gaps that ought to be studied from certain perspectives, starting from a theoretical up to an applied one. The analysis of these issues and gaps, which are detailed in the following paragraphs, would help in better defining the (i) general objective, (ii) the main question and hypothesis of this research together with (iii) subsequent objectives and secondary (complementary) questions.

Shifting from a broad and general definition of the sustainability and resilience towards a more specific one, with a focus on the matters related to the built environment, requires the input of a third “element” that of risk from natural hazards. Facing these hazards properly in terms of preparedness or management would represents a goal itself since it is a key feature in building and developing resilient settlements.

A vast amount of research has been conducted in the last decades with the aim of assessing the risk of a hazardous event. The approaches vary from a specific level, where the risk is analyzed only for a certain hazard, to a multi- approach where several hazards are analyzed simultaneously taking into consideration their common effect in a certain area. Another way of choosing the right approach is by taking into consideration the level of detail required and data availability, based on which the risk is estimated in qualitative or quantitative terms. Despite these approaches the entire process must be seen as a holistic one. Therefore, the integrated variables having a different nature have to be unified to produce an output that is targeted to decision- making structures and actors.

The holistic perspective of the problem at hand raises a number of issues, mainly related to the way the information is transmitted and understood by different experts. Among these experts are the spatial planners which as mentioned in the previous section are easily considered as a fundamental link in matters of risk assessment in an applied context since the information provided by them is more tangible and understandable from a decision-making point of view. Within this perspective the main issue would be that of integrating the information from this assessment into spatial planning in such way to be understandable, reliable and translatable into planning policies and land- use restrictions together with an analysis of the impacts it might have in planning systems and instruments.

Based on the aforementioned issues the research *aim* and *hypothesis* are going to be analyzed based on the following scheme:

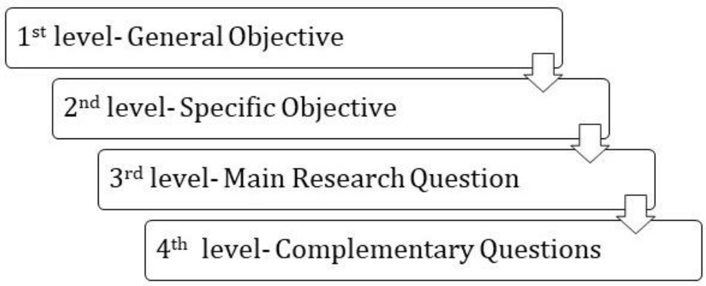


Figure 1.7 Division of the research objective in four different levels

The **general objective** of the research is the focus on assessing seismic risk at a local territorial scale. The state of the art gives a number of methodologies to assess the risk, so a realistic objective would be that of focusing on existing methodologies and theories with the aim of interpreting them in such a way to be easily integrated in different levels among different stakeholders.

The **specific objective** of the research is directed towards the integration of a semi-quantitative risk assessment model in planning instruments by using inclusive information and variables in a multi-scale approach. A multi-scale approach is believed to facilitate the integration of Disaster Risk Reduction in urban planning processes. Such integration can foster the collaboration between stakeholders, help in bridging the gap between scientific and local knowledge and also improve communication and risk perception.

Based on the general and specific objective the **main research question** may be elaborated as follows:

How to effectively integrate risk knowledge within planning instruments towards an inclusive Disaster Risk Reduction (DRR) process?

In order to answer the main question of this research, it is necessary to put forward other **complementary questions**, that will serve as important nodes in creating a path towards the fulfillment of the final objective of the research.

1. How to combine multi-scale information to define the levels of risk?
2. Which are the most inclusive and context-adaptable parameters that can be used to define seismic risk?
3. What is the best way to produce and communicate the risk information for decision-making purposes and to increase risk perception within the community?

1.3 Overview of the Research Methodology

Taking into consideration the main question and objective presented in the previous chapter, a general analysis of the methodological aspects is given. The aim is that of creating a logical framework to be detailed in the following chapters. The addressed problem and research question imply an interdisciplinary nature whose analysis requires a mixing between qualitative and quantitative methods.

A summary of the research methodology to be followed throughout the research is given in the scheme depicted in Fig. 1.8.

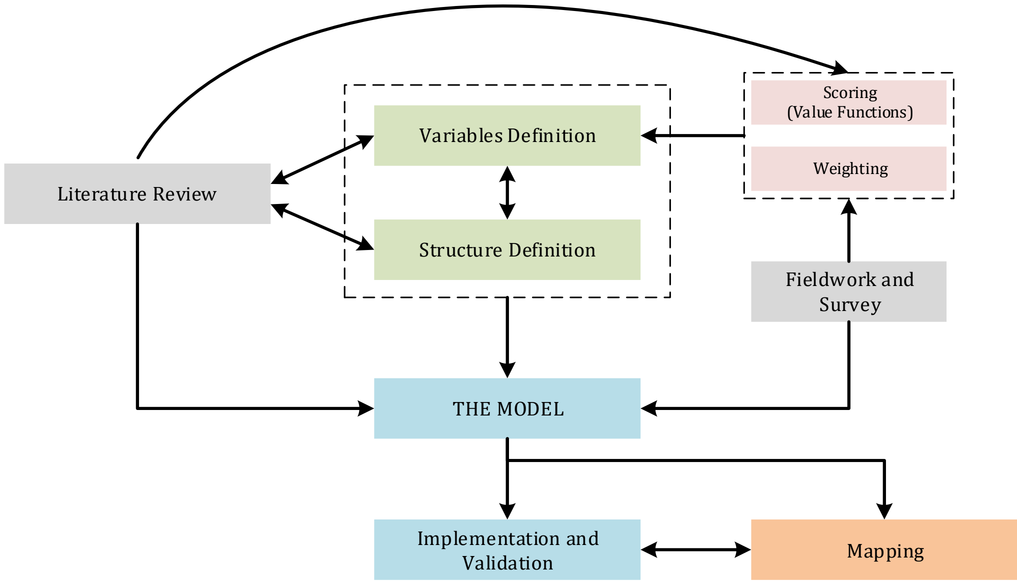


Figure 1.8 An overview of the methodology

The work phase for the entire research, based on the objective and the aforementioned scheme can be divided as follows:

1. **Theoretical Basis- Desk Review**

With the aim of conducting a complete theoretical review and analysis of the research problem it represents the most intense and fundamental part of the research. Printed and online sources will be used in the first place to better define the key concepts of this research (Chapter 2) followed by a complete analysis of each element of the risk assessment (Chapter 3) together with the theoretical aspects related to risk assessment and integration into planning processes (Chapter 4). To conclude the theoretical framework, a detailed analysis of the proposed methodologies and tools for risk assessment is conducted (Chapter 5). The aim is that of creating a complete state of the art and summarizing the advantages and limitations of each methodology. The analysis of relevant literature helps to avoid a positivist approach of the research, giving space for appropriate scientific discussion. It is aimed that through this process, the theoretical basis is developed and the possible knowledge gaps are identified with the aim of improving them. Most of the information that will be used to validate the methodology is going to be collected through such analysis by collecting data from previous studies, reports and maps.

2. **The methodology and implementation**

The proposed methodology and the implementation represent the second working phase of the research. Based on relevant studies from the first part the methodology is elaborated in such a way to be put in a national and also international context. The practical approach includes in itself three main parts; proposal of a structured methodology, case studies and analysis, implementation and validation.

a. Fieldwork and survey studies are developed in parallel with desk studies, the main aim of this part is to collect relevant and accurate qualitative or quantitative data for the selected study areas. Such information can be used to apply the proposed methodology since it is used for both standardization and weighting process. The collection of information in this phase it is done through surveys and site visits, using data from relevant local stakeholders and also working in virtual maps (Google Earth, Google Maps, or other sources). The aim of the survey which will be explained in the following chapters and is found on Appendix B of the research, is to generate a vast amount of data in order to properly determine the relative importance of each variable that has a contribution in the level of seismic risk.

b. Case studies are selected to be as representative as possible to the objective of the research. The main principles in selecting the case studies include; data availability, possibility of site visits and communication with local actors and experts, national and international relevance. After consultations with experts and supervisor two case studies were selected to apply the methodology; Lezhë city for a national focus in Albania and the historical center of Guimarães for the international context of the proposed methodology. Details about each of the selected case study in terms of actual situation, territorial characteristics, building characteristics, hazard elements or any other relevant information as required by the proposed methodology is given in Chapter 7 of the research. Based on the provided information the detailed analysis is performed, in which actual data is combined and translated in relevant indices that would give the level of risk of the studied area. The analysis includes the standardization process and the weighting process.

c. Implementation and validation represent the final part of the research work in which the analyzed data is mapped in a clear, simple and effective way using Geographic Information System. The main aim is to represent the level of risk for each unit of the zone within the case study by ranking and dividing the result into different categories. Other relevant maps could be generated to see also levels of vulnerability and exposure. The output would provide relevant information for pre-screening processes and decision-making purposes giving an initial idea about critical areas where interventions can be prioritized.

1.4 Research limitations

This research aims to focus in one of the most delicate issues within the analysis of natural disasters as it is the processing and integration of the information with a varying nature; from quantitative to qualitative. The main challenges that hinder the effectiveness of measures trying to prevent and reduce the effects of natural disasters have always been related to the way information is combined and integrated to be as comprehensive and easily communicated as possible. A complete risk analysis requires precisely this integration which, on the other hand, from the point of view of different fields of study, is not always easily understandable and often causes confusion and hindering of the process.

Regarding research limitations, one element is the interpretation of information in such a way as to avoid an analysis which would have a qualitative and subjective nature, despite the fact that such elements still leave room for full scientific debate. The weighting and standardization processes used to determine risk levels are generated based on a combination of literature review with professional judgements of various experts, leaving room for further detailing and improvement. Detailed data collection is another limitation that has an impact on the final result. Due to urban configurations, often the level of accessibility for specific objects is not appropriate, posing therefore a challenge in the collection of visual information. In addition, a quantitative and complete seismic vulnerability analysis requires a detailed information for each building, mainly obtained through technical drawings and details together with in-situ tests which in most cases are missing or cannot be performed. Thus, balancing qualitative and quantitative information represents the main challenge of the research.

1.5 Chapters Outline

The research is divided into two main parts; *Part 1- Theoretical Framework* and *Part 2- Methodological Approach* with a total of 8 chapters including the introductory chapter. The first part consists of four chapters (Chapter 2 to Chapter 5), while the second part consists of 3 chapters (Chapter 6 and Chapter 8) as summarized below:

Chapter 1 "Introduction"- Motivation behind the research, main and complementary research questions, research methodology and research perspectives are discussed in the introductory chapter of the research.

Chapter 2 “Unravelling the Concepts”- The main concepts that constitute the core of the research; risk, resilience and sustainability are explained. As complex concepts, the scope is to try to define them for the purpose of the research focusing on natural hazards and disasters.

Chapter 3 “Hazard and Risk components”- In this chapter a detailed classification of hazards is given, followed by an analysis of the main components of hazard and risk analysis. The components are analyzed focusing on earthquakes. The approach in Albania is also briefly introduced.

Chapter 4 “Disaster Risk Reduction and Planning Processes”- Disaster Risk Management, the role of Urban planning in disaster risk reduction and the shifting paradigm from emergency response to prevention strategies are explained in detail in this chapter.

Chapter 5 “Risk Assessment Methods. An overview.”- Representation of some of the most used qualitative and quantitative methods used to assess risk, their advantages and disadvantages and the importance of selecting the appropriate method mainly based on the aim and data availability.

Chapter 6 “The methodology”- A detailed analysis of the proposed methodology in terms of the structure, variable selection, standardization and weighting together with the aggregation process is given in this chapter. The analysis is done based on thorough literature review combined with different experts’ opinions.

Chapter 7 “Implementation”- Implementation and validation of the proposed methodology in two case studies and detailed representation of the results mainly in forms of maps combined with tables, graphs and charts.

Chapter 8 “Conclusions and Recommendation”- General discussion, summary and conclusions of the research together with recommendations are provided in the final chapter of the research.

Part 1

Theoretical Framework

2 Unravelling the Concepts

Dealing with issues related to risks from natural hazards and the methodologies used to assess them require first of all the unravelling of many key concepts. A thorough understanding of these concepts and theories is crucial as it creates a solid foundation for all the upcoming research since the entire work revolves around these concepts and their relationship. First of all, risk itself is a general term that can be defined from different perspectives and before starting to try and assess it, there is the need to first clarify its meaning within the aim of the dissertation. Risk and its assessment, are also part of a greater framework that includes concepts like resilience and sustainable development. As such, literature review that explains these concepts with the aim of defining them in relation to natural hazards and the definition of the complementary relationship is the first step towards starting and conceptualizing methodological approaches.

2.1 Risk: Concept definition and Objectives

Risk is a widely used term that characterizes every activity and event; from the simplest ones to the most complex. When buying an electronic product there is the risk that it may malfunction due to manufacturing problems, when crossing the street as a pedestrian there is a risk that you may be hit and injured by cars, when planning to invest on something there is the risk of failing and losing all of the investment, or many other examples. What is in common in these mere examples is the fact that something unexpected happened that had a negative impact and this would define the general concept of *risk*.

Despite the context, it should be clear that the risk is a result of two main factors; the possibility (likelihood) that an unexpectedly negative event might happen and the impact or consequence that would follow such event. For instance, if in a pot there are 5 folded letters each one of them representing a number from 1 to 5 and in an initial scenario a player wins if he draws 1,3 or 5 and, in another scenario, he wins if he draws 1 or 2 in both cases there is the possibility of drawing any other numbers (representing the negative event) and losing (representing the resulting impact). While the consequence for both scenarios is the same, the risk is greater in the second scenario since the possibility to draw wrong numbers is greater than in the first situation. There are also situations where the possibility of something unexpected to happen is the same while the consequences are different which again would imply different levels of risk.

For the purpose of this dissertation the concept of risk and its assessment is defined focusing on the concept of natural hazards which are considered as:

"... complex phenomena, the causes of which lie to a large extent in human behavior that creates vulnerable communities." (Etkin and Stefanovic, 2005, p. 467).

The term risk that would constitute the core of the research is the one defined by the International Organization for Standardization (ISO 31010) in which:

"Risk is a combination of the consequences of an event (hazard) and the associated likelihood/probability of its occurrence" (cited in European Commission, 2010, p. 10).

Risk assessment on the other hand is stated clearly in the (ISO 31000, 2009) as *"...the overall process of risk identification, risk analysis and risk evaluation*" (p. 17). So, it is a process developed in three separate stages in which the risk is first identified then it is analyzed to determine a certain level of the risk and in the end the estimated risk is compared with a predefined risk criterion (Figure 2.1). The results from the analysis serve as an input to the decision- making processes about (ISO 31010, 2009, p. 10):

- whether a certain action should be taken
- how different opportunities can be maximized
- whether there is the need for treatment of risks
- choosing between options with different risks
- prioritizing risk treatment options
- the most suitable choice of risk treatment strategies that will reduce and eventually bring adverse risks to a tolerable level

The aforementioned definitions place the risk assessment in a scientific framework where its evaluation is based on scientific data, using adequate tools and information. Alongside this scientific approach, for the purpose of risk assessment and management there is the need of carefully dealing with what is known as *risk perception.* Perceived risk is based on individual's personal perception and judgement, and as such emotional reaction prevails over more scientific and reasoned results. (Ferrier and Haques, 2003; Rovins, J.E. et. al, 2015).

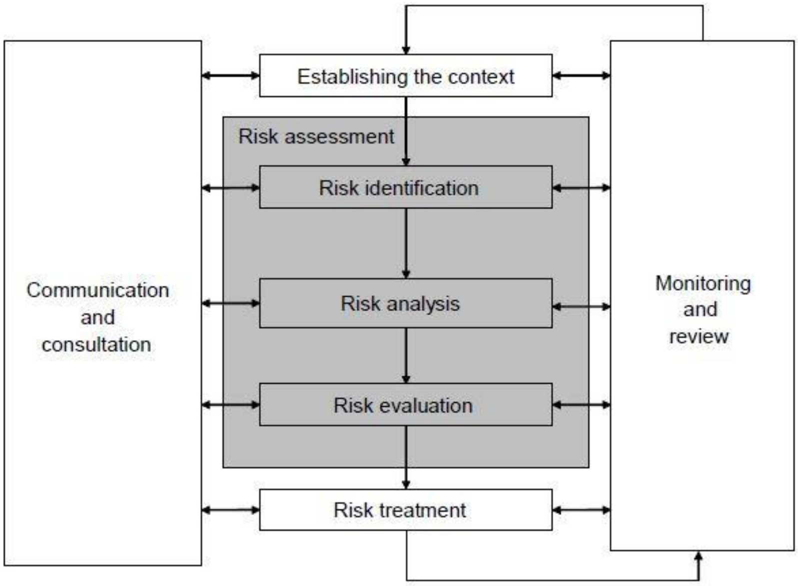


Figure 2.1 The process of a risk assessment (ISO 3101, 2009)

The three stages of a risk assessment are introduced as general processes which will be further explained in the dissertation, but it is important to understand that in order to identify, analyze and evaluate a natural disaster risk there is the need of a thorough analysis of the three components that constitute a disaster risk: *the hazard*, *the exposure (elements at risk)* and *the vulnerability*. The hazard represents the natural event which would have a negative impact while the vulnerability and the exposure represent the consequences of this event in terms of assets affected and their capacity to withstand the given hazard. A generic overview of a risk assessment process including all of the components is given in the figure below:

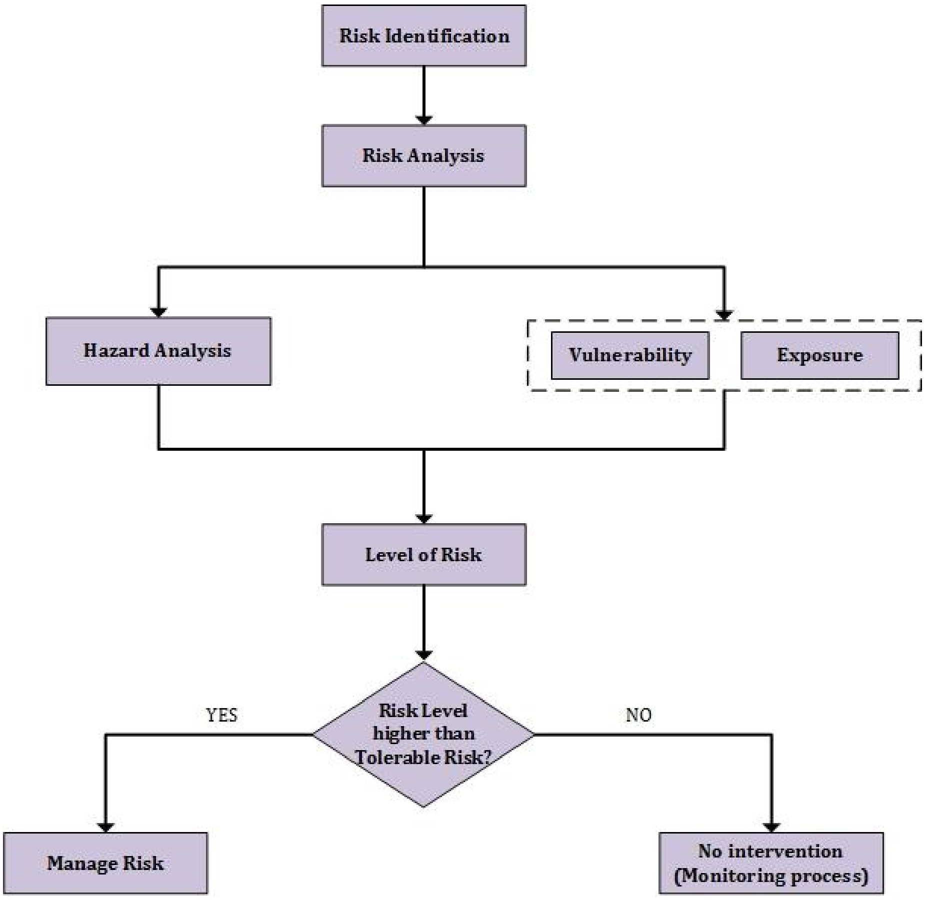


Figure 2.2 Risk assessment process including hazard, vulnerability and exposure

2.2 Definition of sustainability and resilience to natural hazards

The need to improve the quality of life is associated with high demands for the consumption of resources. In the situation where the demands are increasing exponentially day by day and resources are reducing, we talk about what is known as sustainable development. Due to its abstract and complex nature, the concept was carefully studied and defined. Within the numerous definitions and beside the different context and structure, sustainable development is considered a critical concept to the study of human- environment interactions and to the importance of living in harmony with the nature. Furthermore, its aim is to create and maintain prosperous social, economic and ecological systems (Handmer and Dovers, 1996; Mebratu, 1998; Rizzi, Graziano and Dallara, 2018). While development may be easily considered as a "must" to further improve the quality of our lives and accomplish goals, the process itself, as past experiences have shown, not always reflects the interaction mentioned above. In such situation, *"Development thus becomes a process of change guided by the principles of social-environmental justice for all living things present and future, not just humans"* (Silberstein & Maser, 2013, p. 1).

Taking into consideration these principles would ensure what is widely known as sustainable development, whose definition is clearly stated in the report of the world commission on environment and development as:

"… development that meets the needs of present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p. 24).

These principles constitute the elements of a sustainable development and represent *limits* to which humans must adapt and within which the development must be constrained. Understanding and accepting that we cannot modify one part of the system without having an impact on the entire system is the cornerstone of sustainable development. In other words, every change and alteration in the environment is a continual and irreversible process which we cannot bring to the initial condition (Silberstein & Maser, 2013).

For the purpose of this dissertation, it is necessary to analyze the concept of sustainable development from a more technical point of view rather than a moral or social approach. Focusing on a more technical approach would help to further clarify the concept of sustainable development to meet the purpose of this research, that is to emphasize the importance of the risk assessment itself within this development. Since natural hazards represent an external force or a change in a system (neglecting for the moment the nature of duration of the change; an impact or a constant change) it would be appropriate to define sustainable development in terms of system and response to change. Such definition is given by Handmer and Dovers (1996), who considered sustainable development as

"the ability of socio- ecological systems to withstand or adapt to changes indefinitely" (as cited in Toto, 2018, p. 17).

The study of relevant literature gives the possibility of further focusing the concept of sustainable development within the context of natural disasters. Mileti (1996) defines it as the ability to

"tolerate-and overcome- damage, diminished productivity, and reduced quality of life from an extreme event without significant outside assistance" (cited in Cutter *et al.*, 2008, p. 601).

This definition together with that of Handmer and Dovers (1996) would help to converge as much as possible between *sustainable development* and *resilience* concepts.

Resilience too is a broad concept used in various disciplines; from environmental and ecosystems issues to engineering and psychology. As such there exist multiple definitions in the literature, which ought to be studied in order to focus it within the framework of this dissertation. The word "resilient" originates from the latin verb *resilīre "to leap back" or "rebound",* expressing the ability to recover from a negative impact or bad experience. (Merriam-Webster, n.d)

Material sciences elaborated the concept of the term and used it to characterize the physical property of materials to return in their original form after a force that caused deformation was applied, in other words known as *elasticity*. Starting from the concept of elasticity the research on environmental and ecological phenomena were the first to study the topic of resilience (Rizzi et al., 2018). From this point of view there are two different interpretations of resilience; one given by Holling (1973) in which resilience was interpreted as "*the size of disturbance needed to dislodge a system from its stability domain*" and another later interpretation given by Pimm (1984) where resilience was seen as "*the speed of returning to equilibrium following perturbation*" (cited in Perrings, 2006, p. 417).

From the hazards point of view the definition of resilience, as cited in (Cutter *et al.*, 2008, p. 600) means "*the ability to survive and cope with a disaster with minimum impact and damage*" (Berke and Campanella, 2006; National Research Council, 2006). As previously mentioned, hazards in resilience and sustainability analysis are considered as shocks or external factors that have an impact in the proper development and quality of life. If development would be expressed in a graphical way as a "time- depended" variable, in a normal situation it would have a positive trend, always pointing in increasing its value. An outside shock or stress in a certain moment (the hazard) would affect in this development pathway, and is up to mitigation measures, emergency management policies etc. to try and rebound or recover in a way that is time-efficient.

(Conway et al., 2010) in their work defined the patterns of resilience differentiating *stresses* from *impacts* (fig. 2.3). The latter are considered events that happen in a very short period of time (analogous with an earthquake) whose impact in the system are immediate and the sooner stands for long-lasting events, whose effects are not seen immediately, but rather in a long time (analogous with climate change).

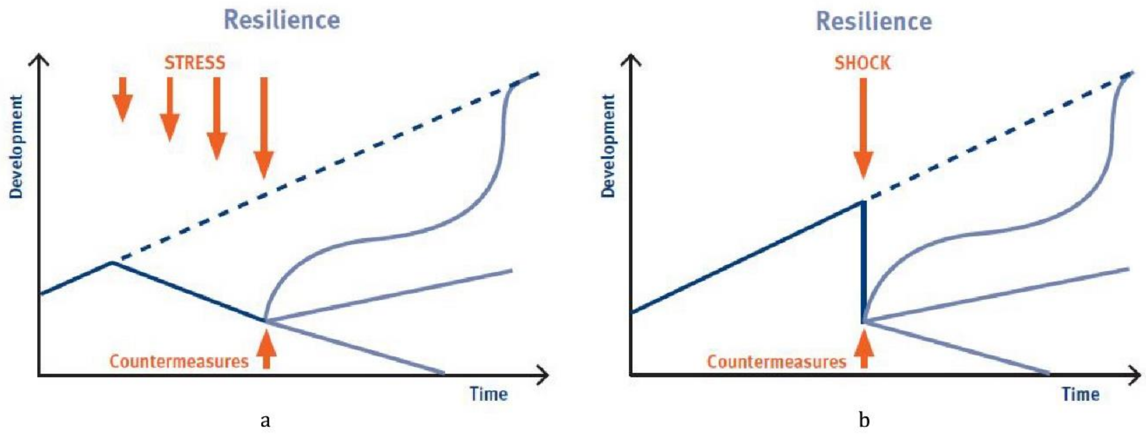


Figure 2.3 a) Effects of stress and b) shocks together with the resilience patterns (Mitchell and Harris, 2012)

Despite many definitions of resilience, there is a lack of understanding of the conceptual comprehensive aspects of it and this represents limitations for the spatial planning and the adoption of policies. Seen from an urban and territorial planning perspective there is an interest in planning anticipatory approaches; that is a transition from reconstruction planning to a preventive one. Territorial resilience in this matter is considered a concept capable of aiding with decision-making processes to improve the usage and transformation of socio-geographical areas. (Brunetta *et al.*, 2019; Wilkinson, Porter and Colding, 2010).

2.2.1 Risk- Resilience relationship

Resilience in terms of natural hazards is not an abstract concept. In fact, several studies have tried to analyze and propose ways of estimating the system's resilience in either quantitative terms or qualitative judgements. The study of (Koren, Kilar, and Rus 2018) for example aimed at proposing a conceptual framework for a quantitative assessment of urban resilience to seismic action. The conceptualized framework consisted in dividing the urban complex system into different components (buildings, infrastructure, community and open spaces), determining quantitative attributes for each of the components and finally by the means of available data, assessing resilience level for each element to consequently obtain the entire urban system resilience using holistic approaches.

Emergency management strategies to natural disasters take into consideration the fact that resilience is not determined for a specific time but on the contrary is time dependent and is analyzed in three different phases: preparedness, response and recovery. To better clarify this dependency resilience has to be seen in two ways: as *outcome* or as *process.* For instance, the resilience is considered as an *outcome* when defined as the ability to cope with a hazardous event and as a *process* when it is studied in terms of continual learning to improve the capacity of handling the hazards (Cutter *et al.*, 2008). At first glance it seems like resilience as an *outcome* is related to a very specific short moment while as a *process* spread in time. In fact resilience is a concept that is *always* intertwined with time within the aforementioned temporal levels.

Within these three phases risk analysis and resilience analysis are complementary and both are very important for informed decision making. Risk helps to quantify the safety of the assets while resilence the capacity of rebounding from the event (Cimellaro, 2016).

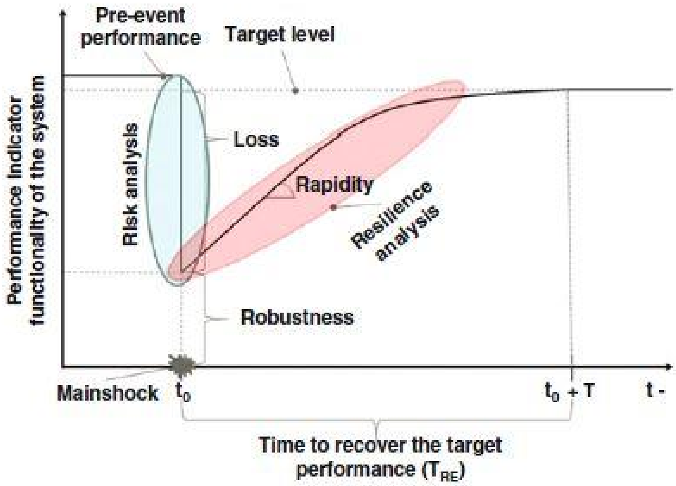


Figure 2.4 The relationship between risk and resilience (Cimellaro, 2016)

From the graph there are two main phases that can be distinguished; the pre- event (including preparedness) and post- event in short term and long term (response and recovery respectively). Each of the phases would have its own indicators that help in measuring resilience. During the first phase, the pre-event performance is given as a function of time. In addition, it is evaluated the capability of the system to face unpredictable events and as such indicators in these phase address the reduction of risks and vulnerabilities (planning and mitigation measures).

The level of disturbance due to a mainshock is highly dependent on the combination of two elements; firstly there is the previous risk analysis which is translated in direct losses and secondly, the robustness of the system itself. Following the perturbation, the ratio of recovery (rapidity) is a function of the resilience, higher levels of which would produce a reduced time to achieve the targeted performance level of the system.

Beside risk and vulnerability there are many other indicators, classified based on several criterias (temporal scale, spatial scale, hazard type etc.), that need to be studied in order to be able to measure the resilience. As stated in the introduction part of this dissertation, the focus is on risk assessment rather than resilience, so these indicators will not be analyzed. The purpose is that of measuring the risk in order to;

"... provide useful input to the resilience analysis and management" (Aven, 2017 p. 536).

3 Hazard and Risk Components

In the previous chapters the definitions of the three main concepts of this research: *hazard, disaster* and *risk* together with their relationship were briefly presented. Hazard assessment represents the first step towards a risk assessment and as such its analysis and characterization is an important link to the entire process that directly affects the outcome. Risk itself is also depended of other elements beside the hazard. As such the implementation and integration into planning processes and instruments requires a complete understanding of each of these elements. The initial part focuses in the classification of the hazardous events based on several criteria. Furthermore, in this chapter is given the transition from hazard to risk for the case of seismic action. In the final part of the chapter the situation in Albania is analyzed. Such analysis is focused on briefly summarizing past historical seismic events followed by a complete representation of the actual situation in terms of disaster risk management.

3.1 Classification of hazards

Hazards can be classified based on several criteria, such as their origin, spatial scale, temporal scale, possible triggering or cascading effects etc. For the purpose of this research the complete classification of hazards is done based on a detailed study and analysis of the relevant literature and websites, with a focus on the proposals made by the IRDR (Integrated Research on Disaster Risk) programme (IRDR, 2014), UNDRR, CHARIM and preventionweb. Following the proposed classification systems, the hazards are divided into *five level*s.

The classification is based on a top- down approach starting from a general classification to a more specific one. In addition, other complementary systems and schemes can be elaborated to account for the temporal scale of the events and the association between them (triggering effects). Detailed information and relevant descriptions for each level will be provided below.

In the *first level*, hazards are divided into three main groups based on their apparent origin as (2.1 Analysis of hazardous events | CHARIM, 2021):

<u>Natural Hazards</u>, representing natural processes or events that occur within the earth's system and can cause damage.

Human-Induced Hazards, representing changes in natural processes within the earth's system triggered by human activities that speed up or worsen damaging events (such as air pollution, industrial chemical accidents, major armed conflicts, nuclear accidents, and oil spills).

Human-made (Technological) Hazards, representing technological or industrial accidents, hazardous processes, infrastructure failures, or some human activities that may result in the death or injury of people, property harm, social and economic disruption, or environmental degradation (toxic waste, dam failures, industrial explosions are some examples). Technological hazards are often considered as subgroup of human-induced hazards.

Further division of the hazards is done in the *second level*. Natural hazards are composed of six subgroups based on CRED classification (Fernando, Liu, & McKibbin, 2021):

- Geophysical (also known as geological), defined as:

  "a hazard originating from solid earth."

- Meteorological, defined as:

  "a hazard caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days."

- Hydrological, defined as:

  "a hazard caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater."

- Climatological, defined as:

  "a hazard caused by long-lived, meso- to macro-scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability."

- Biological, defined as:

  "a hazard caused by the exposure to living organisms and their toxic substances (e.g., venom, mold) or vector-borne diseases that they may carry. Examples are venomous wildlife and insects, poisonous plants, and mosquitoes carrying disease-causing agents such as parasites, bacteria, or viruses (e.g., malaria)."

- Extraterrestrial, defined as:

  "a hazard caused by asteroids, meteoroids, and comets as they pass near-earth, enter the Earth's atmosphere, and/or strike the Earth, and by changes in interplanetary conditions that effect the Earth's magnetosphere, ionosphere, and thermosphere."

On the other hand, according to the same classification technological hazards are further divided as:

- Industrial Accidents,
- Transport Accident
- Miscellaneous Accidents

Regarding the human- induced hazard, an inclusive approach is used. That is, the events that are part of this group are integrated in the other two major groups. Climate change effects (floods, drought, fire etc.), for instance, are integrated in the natural hazards group, while other events of human nature are integrated in the technological hazards group.

For the natural hazards, three additional levels of categorizations are introduced. The analysis of the next three consecutive levels is done simultaneously.

For the geophysical hazards, the *third level* includes three main types of disasters:

- earthquakes, with ground movement and tsunami as disaster sub- type (*fourth level*)
- mass movement, including rock fall and landslide (*fourth level)*
- volcanic activity, with ash fall, lahar, pyroclastic flow and lava flow part of the *fourth level* of classification

The meteorological hazards, unlike geophysical hazards are detailed up to the *fifth level*. The *third level* consists of:

- Storm, in which extra- tropical storm, tropical storm and convective storm are included (*fourth level*). The latter further subdivided *(fifth level)* in derecho, hail, thunderstorm, rain, tornado, sand storm, blizzard, surge, wind and severe storm
- Extreme Temperature, includes cold wave, heat wave and severe winter conditions (snow and frost)
- Fog

In the hydrological hazard subgroup are included:

- Flood, with the *fourth level* consisting of coastal flood, riverine flood, flash flood and ice jam flood
- Landslide with avalanche as a subgroup including snow, debris, mudflow or rock fall
- Wave action in the form of rogue wave and seiche

For the climatological hazard there are three main sub-groups:

- Drought
- Glacial Lake Outburst
- Wildfire with forest fires, land fires (brush, bush and pasture) as a subgroup (fourth level)

Biological hazards consist of:

- Epidemic including; viral, bacterial, parasitic, fungal and prion diseases
- Insect infestation; grasshopper, locust
- Animal Accident

Concluding with extraterrestrial hazards that consist of:

- Impact in the form of airburst
- Space weather in the form of energetic particles, geomagnetic storm and shockwave.

It is important to note that a certain event (fourth or fifth level) can be associated with one or more hazards in the preceding level. An example would be that of a landslide, which as mentioned above can be generated either from an earthquake (part of the geophysical hazard), or from a hydrological or meteorological hazard (heavy rain). Such cases represent the triggering or cascading events based on the source and the corresponding assessment is tightly related to this existing relationship.

3.2 Earthquakes

Earthquakes are the most evident expression of crustal breaking occurring at a variable depth ranging from a few to some hundred's kilometers. This event is driven by fundamental geodynamic processes consisting in the motion of the tectonic plates and the resulting deformation that takes place at the plate boundaries. This is known as the theory of plate tectonics developed around 1960s (Day, 2001).

According to this theory, the earthquake occurs at the moment when the accumulated level of stresses and relative deformations due to the diverging, converging and sliding movement of the tectonic plates overcomes the resistance of the material. The overcoming causes therefore a release of the energy in the form of heat and elastic waves that propagate in all directions representing the source of the shaking of the ground. Since the vast majority of earthquakes are generated at the boundaries their global distribution helps in defining the location of the major tectonic plates and the direction of their movement as shown in the figure below. The map clearly shows how the majority of Europe is affected by these events, Albania and the Balkans being one of the most seismic prone areas.

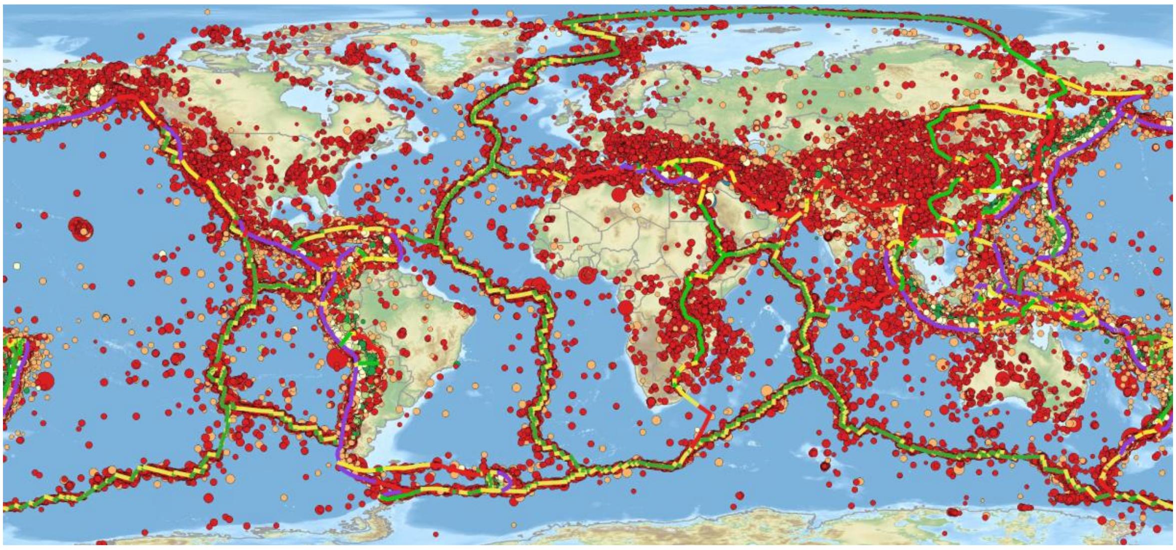


Figure 3.1 Global distribution of earthquakes (1900- 2014) and tectonic plates boundaries (Poljanšek, et al., 2017)

The strength of an earthquake is measured using the magnitude which measures the amount of the energy released from the earthquake and the intensity which evaluates the level of damage. Both, the magnitude and intensity are very important for the hazard assessment. The seismicity of a territory is given based on the magnitudes of different earthquakes that can be generated nearby in relation to their frequency. A high seismicity region is the one that has a high frequency of strong earthquakes.

3.2.1 Hazard Assessment

Seismic hazard assessment or analysis involves the estimation of ground- shaking in a quantitative way using a number of defined parameters. The results of such assessment are tightly dependent on the dataset whose quality, accuracy and quantity directly affect the output and at the same time has an impact in the choice of the proper methodology for the assessment.

Consequently, seismic hazard can be analyzed using either a deterministic approach or a probabilistic approach. The former involves the development of a particular scenario which is used for the evaluation of the ground motion at a specific location, while the latter analyzes all the potential earthquake scenarios together with the likelihood of occurrence, thus providing a framework in which uncertainties related to the size, location and the time of occurrence may be identified and quantified to provide a more complete seismic hazard information (Kramer, S.L., 1996; Schmidt- Thomé, P., 2006 and Poljanšek et al., 2017). For a probabilistic seismic hazard assessment (PSHA), there is the possibility to relate certain ground shaking parameter and their various levels to their corresponding exceedance probabilities in a given interval. For example, the seismic hazard map of Europe developed within the SHARE project illustrates seismic hazard in terms of the peak ground acceleration for a reference ground type A according to EN 1998. The spatial distribution of this parameter is generated for a 10 % probability of exceedance in 50 years, or otherwise a return period of 475 years (Figure 3.2).

The mapping of the components is done mainly on the basis of territorial boundaries and these maps are used to define seismic action in design codes in order to design and build seismic resistant structures. It is important to notice, that these studies and subsequently the maps generated can be carried out in different scales from national up to a local one.

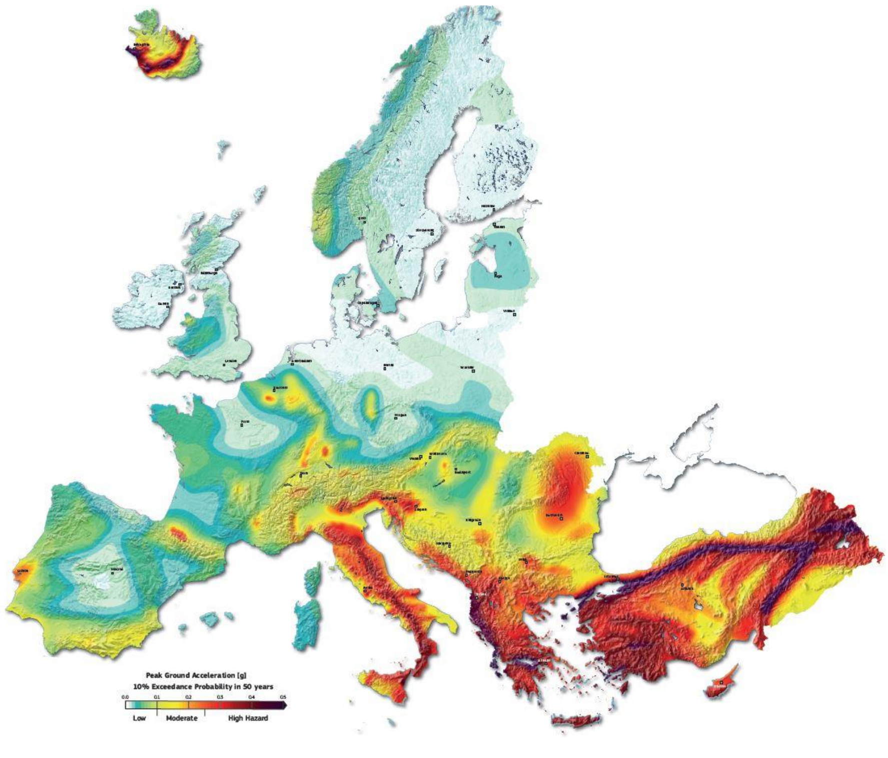


Figure 3.2 The European Seismic Hazard Map in terms of the PGA for a probability of exceedance 10%/50 years (Giardini, 2013)

For the case of Albania, using the probabilistic seismic hazard approach (Aliaj et al., 2010) elaborated two seismic maps in terms of the peak ground acceleration for two levels of probability 10% in 10 years and 10% in 50 years with return periods respectively 95 and 475 years in correspondence with Eurocode 8 (Fig. 3.3). For the probabilistic calculation of the seismic hazard the methodology proposed firstly by Cornell in 1968 and further developed by McGuire was used with the help of the EZ-FRISK software. The main input data for such analysis consisted of what is known as earthquake catalog, elaborated in the Seismic Institute in Tirana depicting earthquakes with a magnitude greater or equal to 4.5 Richter scale.

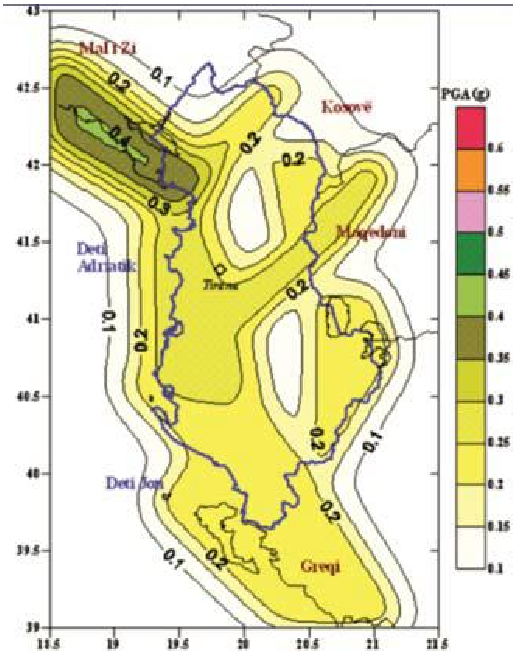


Figure 3.3 Peak Ground Acceleration (PGA) Map for Albania for a probability of exceedance 10%/50years (Aliaj et al, 2010)

3.2.2 From hazard to risk

As mentioned in the previous chapter, risk represents a consequence analysis, where the hazard is combined with exposure and vulnerability to present possible losses in economic, physical or social terms from an event having a certain probability of occurrence. Therefore, the elements of hazard, exposure and vulnerability are fundamental for estimating the consequences of earthquakes which can support several decision- makers in the development of several risk reduction strategies.

In general, exposure is a concept that analyses the hazardous event in terms of elements that are present in hazardous zones and are subject to potential losses. As such, the generation of a detailed and adequate exposure would provide information in terms of the location, type and the value of the exposed elements. Vulnerability, on the other hand, can be defined as the susceptibility of elements exposed to hazards to be damaged and is represented by a set of conditions that result from a number of factors (physical, economic, social and environmental) whose combination can increase the tendency of consequences. Vulnerability is an intrinsic characteristic that can change based on the considered hazardous event.

Both concepts are tightly related to one another, since it is obvious that the assets that can incur losses (including objects or people) are those that are involved in the area where the event happens.

The provided information is a classification of buildings according to a set of defined attributes that are considered relevant for vulnerability analysis including; construction material, number of storeys, construction technique etc. Often this information, that links elements of exposure to a set of defined vulnerability classes is mapped.

The vulnerability functions can be derived from empirical, heuristic or analytical approaches. In the empirical approach the vulnerability function or index is defined directly from regression on historical loss data, in the heuristic approach the expert opinion is used while the analytical approach defines vulnerability by using numerical simulations (Poljanšek, et al., 2017).

It is important to notice the fact that when dealing with vulnerability analysis, one has to take into consideration the vulnerable elements. Different approaches and methodologies are used based on the studied elements for example buildings, bridges, tunnels, network infrastructures. Vulnerability also represents consequences in environmental, social or economic terms.

When studying a large area many of the aforementioned elements are analyzed interchangeably, which consequently makes the problem complex. In many cases to avoid these issues, it is preferred working in terms of representative samples for the entire area. So, the entire building block or network infrastructure are divided in determined classes that would represent them and then the output for the class is generalized for the entire area. Many of these methods focus on defining proper exposure and vulnerability indicators that can be used in the following steps to characterize risk. The output from these approaches gives good preliminary results that can be used for several decision- making processes.

For earthquakes, the assessment of risk is done mainly in probabilistic terms, using PSHA (Probabilistic Seismic Hazard) models, which are featured in many software and studies for seismic risk assessment in national or local levels. The information provided by such assessment beside improving and enforcing seismic codes, or helping in allocation of the funds, contributes also in improving urban planning (Sengezer and Koç, 2005). One drawback of such methods is related to the fact that they ignore social aspects and as such an integrated or holistic risk assessment approach is required.

The risk method that allows to carry out such approach is the semi-quantitative indicator-based approach, not only for seismic events, but for any other natural hazard event too.

3.3 The approach in Albania

Albania is situated in south- eastern Europe on the western part of the Balkan Peninsula and is bordered by Greece to the south and southeast, by North Macedonia to the east, by Kosovo to the north and northeast and Montenegro to the northwest while the western and southwestern part lie along the Adriatic and Ionian Seas. (Fig. 3.4.)

Qualitative historical data recorded through the years together with more modern and advanced survey methods have shown that Albania is potentially affected by several natural hazardous events of a geophysical nature (earthquakes, landslides etc.) and hydro meteorological nature (floods, storms, avalanches, fire forest). The combination of such events with other external aspects result in categorizing Albania as one of the countries with the highest levels of economic damages due to natural disasters, where approximately 86% of the territory is exposed to two or more hazards. (Shala, 2021)

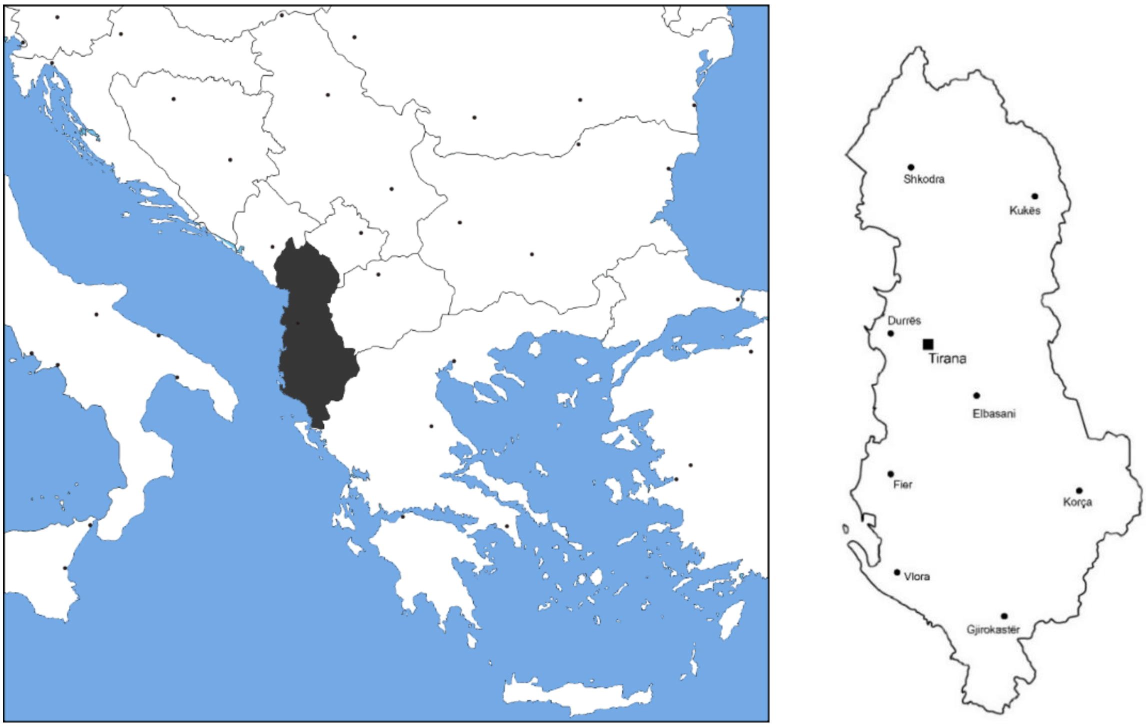


Figure 3.4 Albania location in the Balkans (left) and close up look (right)

Despite the natural character of the events, Albania represents the situation where uncontrolled human activity has had a negative influence in the level of impacts of these events, turning it into a vulnerable country unable to recover properly, as recent events in the last decade have shown. Uncontrolled and unplanned development, poor quality of building materials, informal settlements, lack of updated technical national codes are just some of the reasons to influence in the high level of vulnerability and exposure.

Prior to analyzing and assessing risk, an important step, as previously shown in *Figure 2.1.* is to establish the context. The establishment of the context would set the main criteria and scope of the entire process and also would help in the process of risk management.

The assessment of risks from natural hazards on a relatively small territorial scale, as it is the case and objective of this research, must be put in a wider context whose determination can be made either before or during the development of the risk analysis and assessment.

In terms of hazard in a national scale there have been conducted a number of research projects to try and develop maps that would give the spatial distribution of several hazardous events. These studies have shown that the most likely events to occur and damage Albania are earthquakes and floods as such emergency plans must focus in these two events, not neglecting of course hazards in a smaller scale as landslides, snow or forest fires etc. A desk study review of the UN for the South Eastern Europe listed a number of challenges faced by Albania in the context of natural disaster amongst which the need of setting up an integrated communication and early warning system, improvement of response capacities at the local level and supporting structures for planning (Muralikrishna & Gupta, 2008).

An issue, is related to the risk perception. The extreme natural phenomena are perceived by the citizens as main dangers and threats to their lives and properties, nevertheless this level of perception is not proportional to the level of knowledge regarding the management of such risks, whether natural or technological. A study by (Shala, 2021), through several questionnaires, proved that more than 49.9% of the citizens perceive earthquakes as a risk for their lives, while 22% perceive floods. This perception, unfortunately, is followed by a lack of proper knowledge regarding the management. Among the citizens that filled the questionnaires 75.2% do not have proper knowledge for disaster management in case of storms, while for the earthquakes this percentage varies around 40%. Therefore, communication of risk knowledge among local community represents a challenge for central and local authorities. Improving the appropriate legislative background and the integration of such knowledge in several educational levels together with the adaptation of a national strategy for reducing disaster risk could be the first essential steps to achieve such goal.

3.3.1 Historical overview of earthquakes in Albania

As stated by ISO 31010 to identify risk means *"... to identify what might happen or what situations might exist that might affect the achievement of the objectives of the system or organization.*" (ISO 31010, 2009, p. 12). Amongst many methods to identify risk one of the frequently used is the method known as *evidence- based* an example of which are the historical data. In the context of natural disasters, giving an overview of historical events is an important step in defining risk since past historical events in certain areas represent future potential hazardous events.

This research will use a number of previous studies that give qualitative information of the events and also the data published in the open-source database of EM-DAT for a time period from 1900 up to 2020. The information obtained from EM-DAT will be used to give an overview of the situation in Albania regarding earthquakes due to the focus of the dissertation. To complete the framework, hazard- specific additional information will be presented using other national and international reports and studies.

The EM- DAT creates the database with events that fulfill at least one of the following criteria:

- Fatalities: 10 or more
- Affected: 100 or more people affected/injured/homeless
- Declaration/ International appeal: declaration by the country of a state of emergency and/or appeal for outside assistance

Based on these criteria the following table is elaborated to summarize earthquakes in terms of: total victims, total affected and total economic loss.

Table 3.1 Earthquakes in Albania (1900- 2020) based on EM- DAT criteria

Natural Disaster	Number	Total Victims	Total Affected	Economic Loss ('000 USD)
Earthquake	16	626	219566	793800

When analyzing earthquakes, the term seismicity as a function of earthquakes magnitude and occurrence frequency is used. In general, the seismicity of a country is defined in two separate stages: historical non- instrumental seismicity and instrumental (recorded) seismicity. (Aliaj, et al., 2010).

For the case of Albania, Aliaj, et al., 2010 elaborated an earthquake catalog for events before 1900s based on reports from different authors and reliable historical evidences, and a catalogue for events after 1900s up to 2010 including not only qualitative information, but also recorded data from the seismological stations installed in countries like Italy, Croatia, Greece and also in Albania starting from 1968.

Earthquakes before 1900

12 October 1851

Strong earthquake in Vlorë (southwestern part) where it was reported around 2000 victims. The earthquake caused a tsunami and in terms of its effects it is believed to have reached a modified Mercalli Intensity of IX

10 October 1865

Strong earthquake struck a number of villages in Tepelenë, Berat and Fier cities causing a number of fatalities and damages. Due to this event superficial faults were observed with a width of 10-15m and a length of several kilometers

14 June 1893

The event happened in Himarë where a village (Kudhës) was destroyed entirely. Due to the configuration the event was accompanied with rock collapse. The earthquake felt in Puglia, Italy and according to several authors this earthquake caused a tsunami.

There are reliable evidences that the old city of Durrës (Dyrrachium) was struck by several earthquakes (177 BC, 345 A.D, 506 A.D) that almost destroyed the city.

Earthquakes after 1900

1905 earthquakes

These earthquakes represent one of the biggest series of strong earthquakes in Shkodër, the strongest one occurred on June 1, 1905 with a magnitude of M_s= 6.6. The shock caused about 200 fatalities and 500 injured together with thousands of buildings destroyed or heavily damaged

26 November 1920

The event occurred in Tepelenë city with a magnitude of M_s= 6.4. According to the reports of that time more than 2500 dwelling houses were destroyed leaving homeless approximately 15000 people. The earthquake caused 36 fatalities and 102 injuries.

15 April 1979

This earthquake is one of the strongest to hit the Balkans in the 20th century whose magnitude is estimated between 6.6 to 7.2. The earthquake's epicenter is located in the Adriatic Sea, near Petrovac in Montenegro. The main shock caused 35 fatalities and 382 injuries in Albania. More than 100000 habitants were homeless after the event with more than 17122 houses completely destroyed. The earthquake was so strong, it was felt in all Albanian territory and after this event many institutes worked on improving the existing technical codes of construction for seismic resistance buildings.

26 November, 2019

This earthquake is one of the latest to struck Albania. The earthquake had a magnitude of 6.4 and it lasted for almost 50 seconds. A total of 51 people was killed and around 3000 injured. The earthquake was the strongest to hit Albania in more than 40 years after the earthquake of 1979 and was the world's deadliest earthquake of 2019. The damages where due to poor construction quality and due to lack of proper geotechnical investigation since most damages occurred in ex- marsh zones due to amplification effect. This event brought a series of discussions about the immediate and proper implementation of the European Standards of Construction (Eurocodes).

The following map depicted in fig 3.5 is an adaptation from the work of (Aliaj et al., 2010) in which the spatial distribution of earthquakes with a magnitude $M_s \geq 5.0$ in the timeframe 1900-2005 is given. In addition to the registered earthquake in that period, major earthquakes happening between 2005- 2020 were added manually based on data obtained from bulletins published by IGEWE (Institute of Geosciences, Energy, Water and Environment).

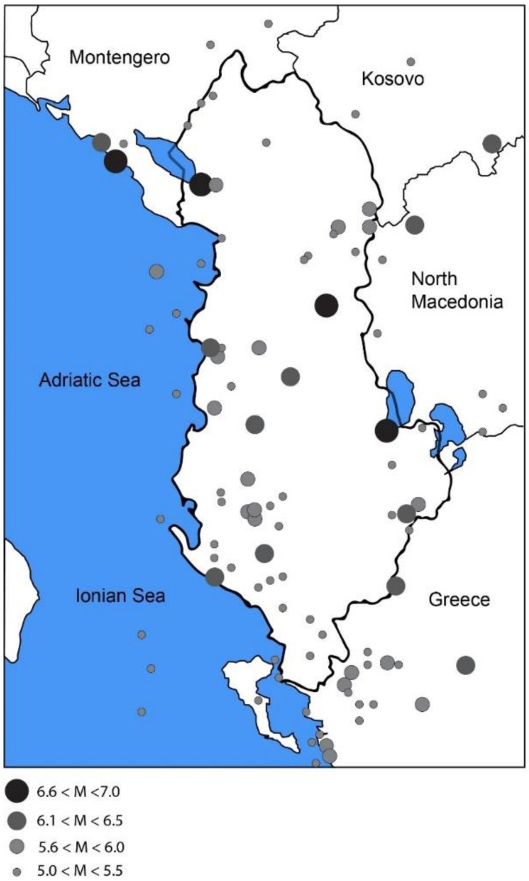


Figure 3.5 Earthquake's epicenters in Albania during 1900-2020 (adapted from Aliaj et al., 2010)

3.3.2 Disaster Risk Management. The actual situation

The report for the South Eastern Europe disaster risk management and adaptive initiative, using national reports on the status of disaster reduction that were developed in 2005 for the World Conference on Disaster Reduction in Kobe, Japan tried to assess the status of each SEE country.

The status for each country was given taking in consideration four elements each one of them having their own variables rated qualitatively into four categories: good (G), satisfactory (S), needs improvement/ not available (N) and under construction (U). The analyzed elements together with their variables for the case of Albania are summarized below (Muralikrishna & Gupta, 2008):

1. Emergency Preparedness
    a. Emergency response planning (S)
    b. Exercises (N)
    c. Public awareness (S)
    d. Communication & information management systems (N)
    e. Technical emergency response capacity (N)

2. Institutional Capacity Building
    a. Decentralized emergency management system (N)
    b. Community participation (N)
    c. Legislative Framework (S)
    d. Training, education & knowledge sharing (S)
    e. International cooperation (G)
3. Risk Mitigation Investment
    a. Warning and monitoring systems (N)
    b. Hazard mapping and land- use planning (N)
    c. Code refinement and enforcement (N)
    d. Hazard- specific risk mitigation (S)
4. Catastrophe Risk Financing
    a. Ex- ante funding arrangements (N)
    b. Catastrophe insurance pool (N)
    c. Reserve funds (N)
    d. Contingent capital facility (N)

The results show that in most variables (12 in total) Albania is rated as “needs improvement/not available” followed by a satisfactory level in 5 variables and only 1 good level.

Events over the past few years (the November 2019 earthquake and the pandemic) have shown that Albania needs to develop and implement a comprehensive strategy and action plan to strengthen the country's resilience to the various existing risks and possible future impacts.

The actual legislative framework for natural disasters and planning includes *Ligji 107/2014 “Për planifikimin dhe zhvillimin e territorit” (*Law 107/2014 “For planning and territorial development”*)* modified in 2019 with *Ligji 42/2019 “Për disa shtesa dhe ndryshime në ligjin Nr. 107/2014” (*Law 42/2019 “Regarding some additions and changes in Law No. 107/2014”*) together* with *Ligji 45/2019 “Për mbrojtjen civile”*. (Law 45/2019 “For civil protection”).

This legislative framework specifies that for the Republic of Albania there are two levels of planning: central and local each one of them having their own documentations (Law 42/2019) and that for the case of natural hazardous event the aim is to reduce risk in accordance with the SENDAI framework by (Law 45/2019 article 8):

1. Correct identification
2. Periodic risk estimation
3. Monitoring

Article 9 of the same law specifies that risk evaluation is dependent on the type, characteristics and origin of the hazard, the levels of exposure and vulnerability and its evaluation is done in central, county and local level.

The first national document for territorial planning was elaborated in 2015 and addresses planning issues in an integrated way, analyzing the Albanian territory as a whole. The document gives a strategic framework regarding sustainable development for a 15 years' period (2015-2030) with an importance in the economic, political and legislative point of view for Albania.

To better understand the Albanian civil protection system based on the work done by (Nazinyan, A. and Spahiu, E., 2021), the following schematic view is elaborated showing the relationship between institutions, commissions and organizations in different levels from central to local:

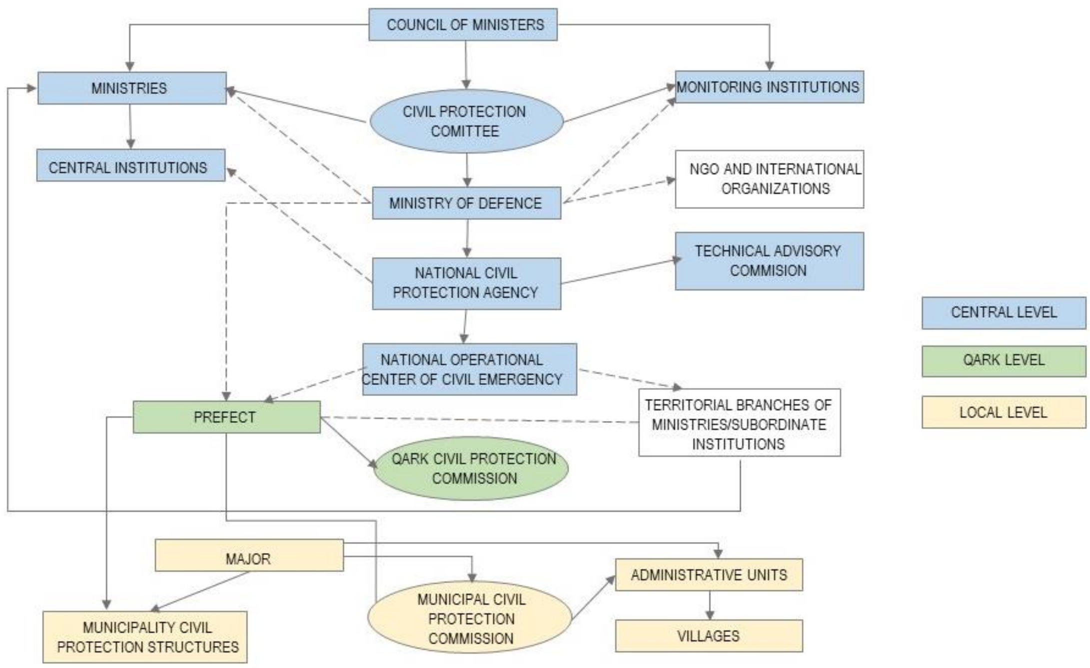


Figure 3.6 Civil protection system in Albania (adapted from Nazinyan, A. & Spahiu, E., 2021)

Research and projects have been conducted to improve the situation in terms of risk reduction and management. Nevertheless, there is still room for a substantial improvement. Among the many aspects of DRM and DRR, special attention should be paid to the way in which comprehensive risk information is transmitted to decision-making processes at the local level. In Albania there is a lack of such information and practices. In cases where there are some minor attempts they are found in the Environmental Assessment (known as VSM) documents in terms of hazard mapping, but not in terms of risk.

In addition, the hazard assessment is not participatory. The participatory assessment is an important aspect since relates to good historical data that can be used to evaluate exposure and vulnerability. The information, delivered and elaborated properly can be fundamental in taking appropriate measures to reduce losses to these natural phenomena.

4 Disaster Risk Reduction and Planning Processes

The disasters due to natural hazards represent the "conflicting" relationship between people and the environment. The effects are undoubtedly proportional to the magnitude of these events which, depending on the hazard and data availability, are studied mainly in terms of historical data and probabilistic analysis to express them in a quantitative way for further analysis. On the other hand, these effects are mainly due to the vulnerability of the populated areas, which as mentioned by (Fleischhauer, Greiving, and Wanczura 2007) is partly due to years of spatial planning policies failing to properly take account of hazards and risks. This chapter analyses in detail the theoretical framework related to disasters, disaster risk reduction and management and also the importance of the integration of these concepts and practices into planning processes and instruments in a local scale.

4.1 A shifting paradigm

Back in time, disasters were seen by the early societies as products of the unpredictability and devastating nature of the hazardous events that were beyond the control of the humans and as such, cultural and social components were not taken in consideration. Nevertheless, beside the believes, there are many examples of societies protecting their people and resources which may be seen as a two-phased process. The first phase includes the anticipation of possible disasters, based on the obtained knowledge of the hazardous events while the second one includes the investment in protecting measures.

The need to predict, anticipate and mitigate the disasters does not represent a modern concept, on the contrary, it dates back thousands of years ago. The first seismograph was invented by the Chinese that could detect the ground's movement during an earthquake, showing the direction of the earthquake is one example. The seismograph consisted of a bronze device with eight dragons and eight toads pointing in different direction. Each of the dragons had a copper ball in their mouth, and with the help of a sensitive pendulum inside the device, in case of an earthquake, the ball would fall from the dragon mouth to the toad below making a noise and therefore giving the direction of the earthquake based on the position of the dragon it fell (Chang & Chang, 2021). The Chinese also constructed protective dykes to anticipate flooding from the major rivers that could harm the crops and risk their lives.

Another example of such approach is the creation of the terraces on steep slopes by the Incas between 13th and 15th century in order to conserve scarce soil and water for their crops. By doing so, not only farming was improved but also the stability of the slope itself.

Latter examples of such approaches include the construction of systems of sea dykes by low-lying countries located in Europe since the 18th so that the usage of land for settlement could be enhanced and inhabitants could be protected from flooding, or the anticipation of drought and its consequences by policy measures in India in 1874 (UNISDR, 2004).

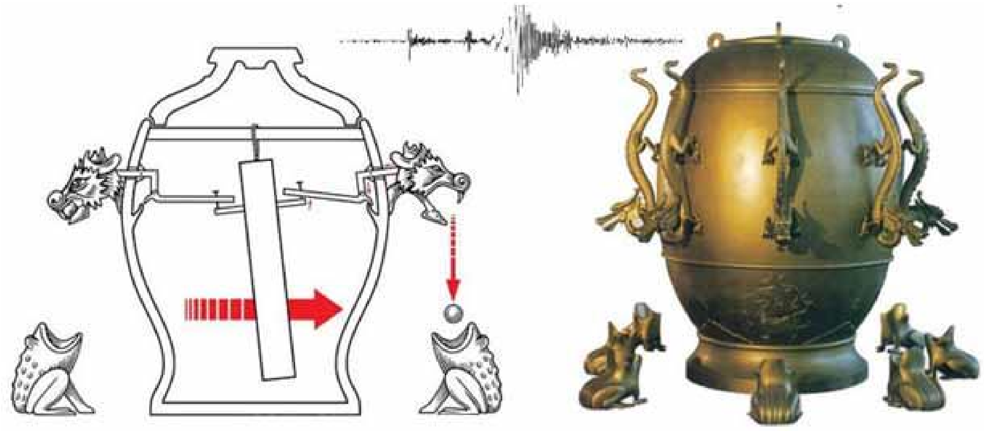


Figure 4.1 Cross- section (left) and view (right) of the first Chinese seismograph (Landicho, 2021. Retrieved April 12, 2021)

The delicate and abstract subject of disaster risk and disaster risk reduction in the modern era draws its relevance from earlier contributions and previous practices and in the last decades there has been a continuous evolution in this aspect. A "traditional" approach has been that on preparation and improvement of capacities for an effective response and recovery after the disaster. Even though the response to an event and the recovery period are fundamental aspects that need to be enhanced, the main issue is that with the rate of development of the modern societies and the severe inequalities amongst them they cannot afford to value their assets after they have been lost. This is the reason why, in more recent years, due to the increased frequencies of these events there is a shifting paradigm from an emergency response and reconstruction towards a prevention strategy (UNISDR, 2004; Sutanta et al., 2010), Such strategies, on the other hand require a holistic approach that emphasizes vulnerability, exposure and risk factors as fundamental elements of disaster risk reduction, or disaster risk management. The policies and measures need to be implemented first of all with the aim of enabling societies to be resilient to natural hazards and in the same time ensuring that this development does not increase the vulnerability. However, despite an increase in hazard exposure in higher rates than the decrease in vulnerability, and although an estimation by the European Commission shows that for every Euro spent in ex ante measures, four to seven Euros are saved there is yet a lack of significant shift of the focus spending more on post-disaster recovery (Aakre et al., 2010; Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark, I., 2017).

The gaps that need to be bridged to properly shift the focus towards ex ante measures include political commitment, technical aspects, financial rationale, cultural awareness and environmental sensibility and the key to a successful and effective holistic approach in the form of a partnership and collaboration between policymakers, private sector actors and scientists is the common understanding of the risk.

4.2 Elements of a Disaster Risk Management

Risk as a concept was described in detail in the second chapter with the main aim of trying to give the close relation it has with the abstract concepts of resilience and sustainability. For the purpose and the objective of this research there is a need to also further analyze and explain the concepts of Disaster Risk Reduction (DRR) and Disaster Risk Management (DRM) since the targeted output is tightly related to them. Although often used interchangeably and considered complementary they differ from one another. The UNISDR Terminology on Disaster Risk Reduction give clear definitions for both DRR and DRM, respectively as:

> *"The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events." (UNISDR, 2009, p. 10)*

> *"The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster." (UNISDR, 2009, p. 10)*

Disaster Risk Reduction represents the policy objective and aim with specific goals and objectives defined in different disaster risk reduction strategies and plans. On the other hand, Disaster Risk Management can be thought as the implementation of DRR policy objectives aimed at minimizing the impacts disasters have on individuals and society. The activities included in a DRM process are in line with the Sendai Framework for Disaster Risk

Reduction 2015-2030 (explained in the following part) and are designed to (Poljanšek et al., 2017):

a. Reduce existing risk

b. Prevent future risk

c. Manage residual risk

The elements of a DRM, known also as measures, needed to achieve the aforementioned objectives are given in the following scheme:

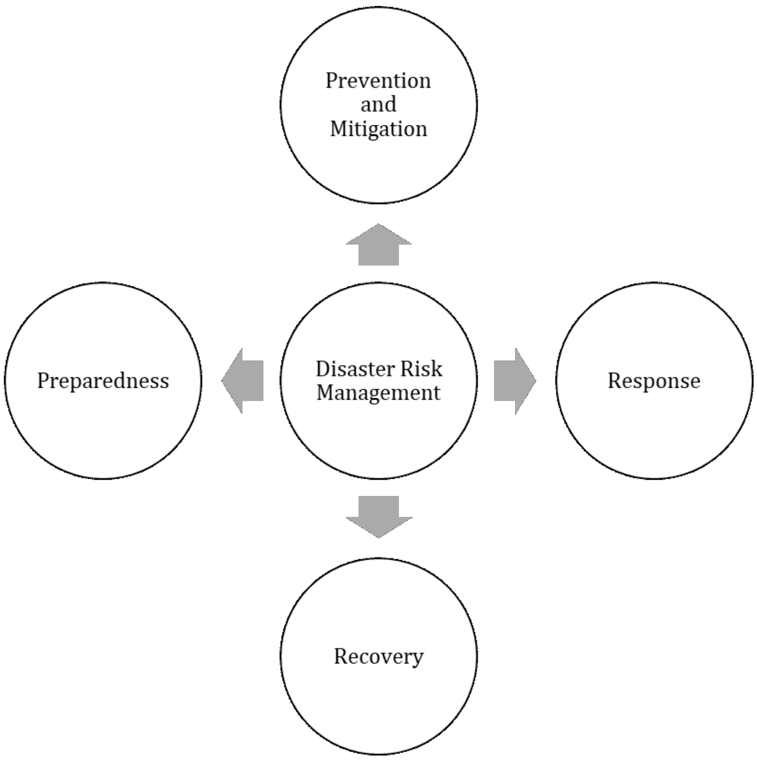


Figure 4.2 Elements of a Disaster Risk Management

Mitigation and preparedness are measures implemented before the disaster while response and recovery represent measures after the disaster.

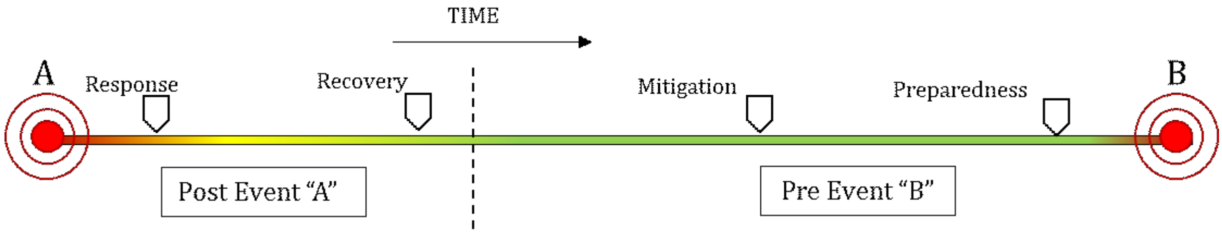


Figure 4.3 Elements of a DRM as a function of time

4.2.1 Mitigation and Prevention

Within the DRM framework both, mitigation and prevention represent ex ante interventions. The former is aimed at a reducing or lessening the adverse impact of a hazardous event while the latter at completely avoiding it. These adverse impacts often cannot be fully prevented but rather lessened by several strategies and actions, so the task is transformed into that of a mitigation. This is the reason why often mitigation and prevention are used interchangeably.

These interventions can be achieved using a number of *structural measures* representing engineering solutions like the construction of resistant structures or modification of natural environment and *non- structural measures* known also as “soft methods” (Coppola, 2015) including adaptation of regulations, community initiatives, modification of natural environment without engineering interventions etc.

It is a matter of fact that the adaptation of mitigation measures is more likely when there is the possibility of obtaining first of all clear and correct information. Within this issue risk assessment itself plays an important role through the application of the information provided from such assessment and analysis in several evaluation and decision-making processes to prioritize future actions for reducing the risk.

As mentioned in the introductory part of the research, due to many reasons settlement and other economic developments are concentrated in hazard- prone areas and the challenge is that of developing these areas in such ways that the vulnerability to natural hazards is managed so that it limits the risks imposed to human life or physical structures in general. Interventions and management strategies aim at tackling elements related to exposure and vulnerability and thus mitigate the risk.

In this aspect, spatial planning policies and regulations can play an important role as they directly influence in the levels of exposure and vulnerability. The elaboration of the data in the form of risk maps can also be very useful in prioritizing land use planning, restricting development or imposing additional measures. Nonetheless, there is an essential need to further integrate risk assessment into spatial planning processes, as clearly highlighted in the Sendai Framework.

4.2.2 Preparedness and Response

Preparedness and response are tightly related to one another since the former represents the knowledge and capacities built in time by the government, professionals and communities in order to properly and effectively anticipate and *respond* to the impacts of an imminent hazard. The response which as mentioned, is a certain goal of preparedness and represents the emergency services provided during or immediately after a disaster.

Both, disaster preparedness and response have evolved around a risk- based approach and within this context a risk-based governance plays an important role as a means to operate in a more efficient way taking into consideration the lack of resources. In addition, the involvement of the community is essential. As stated in (Alexander, 2002 cited in Poljanšek, et al., 2017, p. 471) a switch of the focus towards civilian disaster preparedness and response recognizes that disasters can be mitigated successfully if to the community is given the power to take responsibility for their own safety.

4.2.3 Recovery

Between response phase and recovery phase there is no clear-cut that divides where one ends and where the other starts. Nevertheless, the task of recovery essentially begins soon after the emergency phase has ended and is a long-term process with the aim of improving the facilities and living conditions of affected communities. In this context following the SENDAI Framework guiding principles, it is critical to reduce disaster risk by "Building Back Better".

This can be done by integrating mitigation measures in the recovery phase; an example might be the proposals to change or improve building codes and/or land use plans. As an interactive problem (Berke and Campanella, 2006), recovery requires a coordination between stakeholders including; local officials, affected community, private sector and community participation in general.

4.3 Sendai Framework for Disaster Risk Reduction (SFDRR)

The Sendai Framework for Disaster Risk Reduction (2015-2030) adopted at the Third United Nations World Conference on Disaster Risk Reduction from 14-18 March 2015 is an international document, successor of the Hyogo Framework for Action in 2005 (UNISDR, 2015). Even though it is a non-binding agreement, by setting a far reaching and people- centered approach to DRR and with the aim of guiding the multi-hazard management of disaster risk in development at all levels and across all sectors, it represents a core document for every Disaster Risk Reduction and Disaster Risk Management effort in every scale.

In general, *the intended outcome* of the framework includes the substantial reduction of disaster risk and losses in lives, livelihoods and in the physical, socio-cultural and environmental assets. This outcome is considered achievable by following *a main goal*, that of preventing new and reducing existing disaster risk through the implementation of a number of integrated and inclusive measures (economic, structural, legal, educational etc.), which on one hand would reduce hazard exposure and vulnerability and on the other hand would increase preparedness for response and recovery, consequently strengthening resilience.

The implementation of the present document is guided by 13 principles, a summary of which is given in the following diagram:

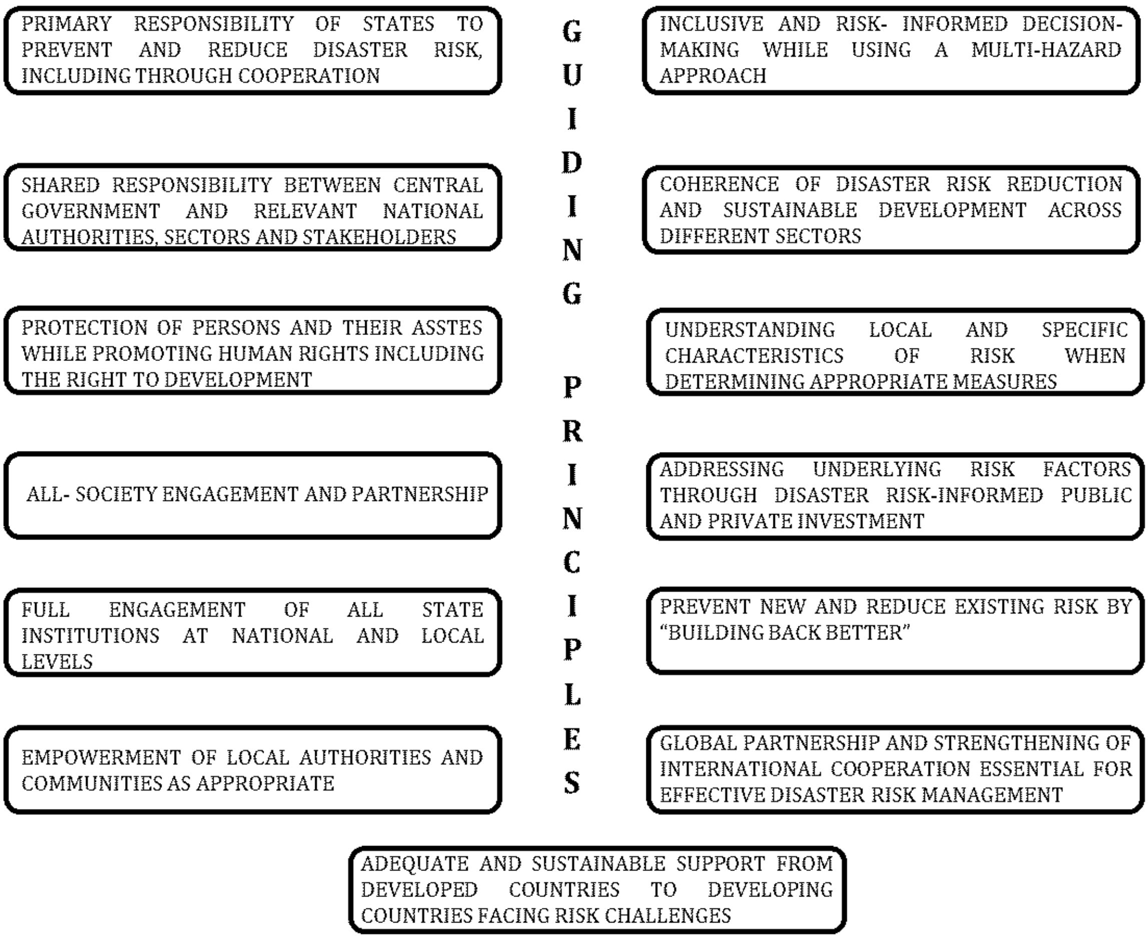


Figure 4.4 Guiding Principles of the Sendai Framework (adapted from SFDRR, 2015)

Two of the principles are tightly related to the empowerment of local authorities and communities through decision- making responsibilities and to the need of accounting for the local and specific characteristics of the disaster risk in order to properly determine measures to reduce risk. Based on the aim and goal (chapter 1), these are the two main principles that will lead the research.

The document, in pursuance of the expected outcome and goal, focuses the action in four priority areas, each one of which is further detailed relevant to the national and local levels:

1. **Understanding Disaster Risk**

According to this priority, the practices and policies for DRM should be based on an understanding of disaster risk. That is, the risk should be analyzed and understood in terms of all its constituting elements: exposure, vulnerability, capacity and hazard characteristics. The knowledge can then be used for several purposes like pre-disaster risk assessment, prevention and mitigation, or for preparedness and response.

Achieving this priority requires a number of actions to be taken at the local level and national level and given the relevance to the research, some actions at the local level include:

- Developing and periodically updating and disseminating location-based disaster risk information (including risk maps) to decision makers and the general public.
- Promoting and improving dialogue and cooperation among scientific and technological communities
- Applying risk information in all its dimensions of vulnerability, capacity and exposure of persons, communities and assets, as well as hazard characteristics in order to develop and implement disaster risk reduction policies.

2. **Strengthening disaster risk governance (DRG) to manage disaster risk**

Disaster Risk Governance or simply DRG is defined by the United Nations as:

> *"The way in which the public authorities, civil servants, media, private sectors and civil society coordinate in communities, and on regional and national levels in order to manage and reduce disaster and climate related risk" (UNDP, 2012).*

The strengthening of DRG according to SFDRR is necessary to foster collaboration across mechanisms and institutions for the implementation of instruments that are relevant to DRR and sustainable development.

The action to be taken at a local scale relevant to the research includes the integration of DRR within and across all sectors together with the review and promotion of the coherence of further developments of national and local frameworks of laws, regulations and public policies which guide the public and private sectors.

3. **Investing in disaster risk reduction for resilience**

This priority focuses on the important role public and private investment in DRR have in enhancing resilience, which on the other hand serve as drivers for innovation and growth. Among a number of actions to be taken in order to achieve the third priority, two of them have a focus on the promotion and mainstreaming of disaster risk assessment into land-use policy, development and into the implementation of tools that are informed by changes in terms of environmental and demographic elements.

4. **Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.**

One of the key elements in building back better is the preparedness, recovery, response and rehabilitation phase. The integration of DRR in planning processes and specially of risk analysis is a part of the preparedness in institutional level since it offers the possibility of information for experts, municipalities and for the community

4.4 The integration of DRR in Urban Planning

Planning is tightly related to the process of construction and urbanization, that is with the proper evaluation and planning of human interventions in the territory with the aim of developing new areas. These interventions placed in an urbanization context, influence and are mutually influenced by natural and biological disasters. Consequently, planning cannot be accomplished without taking into consideration this mutual relationship.

According to (Fleischhauer et al., 2005, as cited in Sutanta, Bishop and Rajabifard, 2010) the role and contribution of spatial planning in disaster risk reduction can be seen in four different aspects:

1. Preventing and controlling future development in areas that are considered highly susceptible to disasters and have a history of such occurrences and also ensuring that areas designated for emergency response and retention are kept free from any new development.

2. Classifying and categorizing disaster prone areas based on land use suitability by taking into account that the levels of acceptable risks for disasters differ based on different land use classes.

3. Regulating land use or zoning plans with legally binding status.

4. Hazard modification where the risk is reduced using different engineering methods based on the information given by spatial planners

As a holistic process, spatial planning should take in consideration several factors including the physical environment, demographic data, political stability, economic factors and natural hazards. Despite this the city's or region's vulnerability towards hazards is not properly assessed during the planning stage focusing more in the social and economic factors (Sharma and Miyazaki 2019). It eventually affects this community's ability to achieve a sustainable development since large amount of financial resources need to be reallocated for emergency and reconstruction program (Sutanta et al., 2010). In this context, building resilient cities requires for planners to approach DRR as a cross-cutting issue in matters of policy planning, design decisions or investment decisions.

Planning can play an important and integral role in almost all of the Disaster Risk Management and Disaster Risk Reduction elements, from mitigation and prevention up to the response and emergency management. Thus, incorporating spatial planning into all the corresponding aspects of DRM and DRR can promote community resilience and subsequently reduce the levels of vulnerability to natural disasters. The diverse, hierarchical and integrated infrastructural systems where every hierarchical element of these systems has more than one alternative (several streets have access to the same area), or public spaces and their adaptation to accommodate specific functions in case of disasters are just some examples of the actions taken during the planning process.

The territorial aspect of the resources is the main reason why planning is tightly related to the DRR. First of all, planning is an instrument that decides how these resources will be used, preserved and maintained in accordance with human interests and secondly it is a process that at least theoretically, guarantees public interest, promotes and stimulates collective action. It is under this point of view that the DRR is not a process differentiated from planning, it is rather a dimension inside planning. It is important for planners, decision-makers and civil emergency experts to understand this.

Another interrelationship between planning and DRR is due to the temporal dimension they both have, since planning aims to achieve sustainability and resilience it is possible that through several proposals, it may improve risk profiles for different urban or rural territories.

Another crossing point between planning and DRR is the legislative background. Although the legal basis is specific, there are relevant elements that can and need to be intertwined. An example would be to turn risk reduction analysis and strategies into planning criteria.

In addition, the recurrent and iterative nature of planning processes starting from the definition of problems and actual needs based on the gathered information, continuing with the identification of possible options and based on testing selecting the most appropriate one and ending with the implementation and the monitoring (Suri et al., 2020) gives the opportunity of integrating disaster risk elements which in previous steps might have not been taken properly into consideration.

Finally, planning has a key role to play in the financial aspects. During the response and emergency phase there is usually the need for more financial resources than those planned and a way to lower such cost is through prevention and mitigation measures taken into consideration in planning processes.

Looking at the spatial planning practices in Europe little attention is paid to risks approaches. In cases where it might have taken into consideration, they deal with single hazards risk, focusing more in the hazard component based on complex technical information that would give only the likelihood of the event to happen in the form of maps rather than the risk in terms of consequences.

Despite the fact that this information is important for planners to have a good understanding of the "spatial layout" of the event, it is purely technical and does not give information regarding the consequences associated with the event. The quantification of the consequences would complete the risk assessment framework and give valuable data regarding further disaster risk management plans and strategies. This issue is more tangible nowadays since the planners are facing challenges related to growing population, the scarcity of suitable space and a growing risk from natural hazards.

In several literatures there is this criticism towards the approach planners and emergency specialists have regarding disaster risk reduction. Despite the fact that planning and risk reduction are conceptually tightly related to one another there are gaps related to the implementation. The nature of these gaps is historical and relates to the way the professions have evolved. Historically, planning has been seen as a future-oriented approach, independent of the risks that may occur which we cannot anticipate. Basically, planning is considered as a probability theory, adding to this probability the hazardous events, the issue at hand gets complicated. On the other hand, civil emergency has a focus on the emergency phase rather than prevention.

In both aforementioned areas it is not yet fully understood that it is better to work in reducing the risk before an event rather than allowing the crisis to occur and then deal with the recovery phase. A downside of such approach is that risk is based on scenarios that might not even happen and therefore from a financial point of view the expenses are based on predictions, which is not appealing and in many cases is not a priority for political agendas.

The implementation of a methodology that assesses the risk from hazardous events gives the possibility of creating a transparent and structured process that would firstly lay the foundations for developing repeatable and modifiable future effective policies and strategies and secondly would allow more robust planning decisions for a particular development or activity (Rovins, J.E., et al., 2015; Saunders, Beban and Kilvington, 2013).

5 Risk Assessment Methods. An overview

The main aim of a risk study, including the analysis, assessment and management is the protection of the assets against a potential damage caused by natural events. As aforementioned, such process is complex and requires knowledge and expertise from different specialists.

Risk in the context of this research is considered as a disaster that might potentially happen in the future, as such the accurate prediction of the hazards and the eventual consequences is of the utmost importance. However, such prediction is very challenging, taking into the consideration the uncertainties characterizing these events. The field of risk analysis is not considered as a purely scientific one, rather as a field that would necessarily include judgements over issues like that of risk tolerances and management strategies (Poljanšek, et al., 2017). The individuals, policymakers or any other specialist that use the output of a risk assessment process for decision making purposes and for the proposal of mitigation measure, in many cases are not risk specialists. Therefore, rational decisions by these individuals require a comprehensive and transparent process.

In the risk research field, there is no correct way or methodology, since the selection and application are determined on the basis of a variety of factors, amongst which the *main goal*, *relevance* and the *available data*. The objective of this chapter is precisely to give an overview of risk assessment methodologies based on a thorough review of the relevant literature. In addition, this chapter will introduce from a theoretical point of view key aspects related to the generalized framework of the selected methodology for this research. Selection of the indicators, relevant evaluations and more practical aspects that are related to the applied part of the research will be analyzed in the following chapter.

5.1 The Probabilistic Approach

The entire process of risk assessment includes three steps (see Fig. 2.1). Each of the specific steps have their own defined methods and approaches. Two general approaches that characterize the risk assessment process are the *deterministic* and *probabilistic* approaches. Such classification analyzes the process as a whole and serves as a starting point for other additional detailed classifications which are based on the techniques used for assessing the risk or the way the information is elaborated.

The probabilistic approach represents the most advanced and sophisticated approach to assess risk. Due to the quantitative nature, it is also defined as a quantitative approach mainly known as QRA, which stands for Quantitative Risk Assessment. In addition, following the sources of uncertainties that characterize the entire process the term stochastic is widely used.

The main aim of such approach is that of analyzing and modelling all potential events with their associated probabilities in terms of frequency and severity, therefore giving the opportunity for an advanced cost- benefit analysis and consequently numerous risk management strategies. The assessment of such probability functions allows to run numerous simulated events and therefore assess the loss at different levels. The relationship between the losses and the frequency of the event for a certain scenario is given in the form of a graph, widely known as *risk curve*. As stated by (Birkmann, 2013) the way the risk curve is generated depends on the main objective of the entire process, for instance it could represent losses in economic terms or losses in terms of the population.

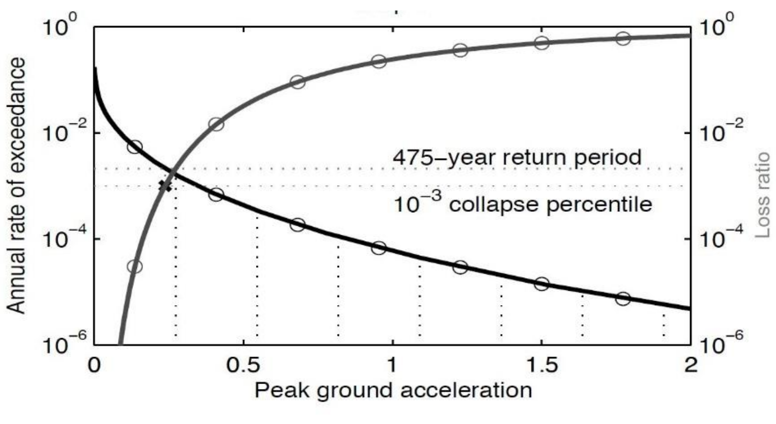


Figure 5.1 Hazard curve and loss ratio curve as function of the peak ground acceleration (Silva, et al., 2016)

The process of risk assessment is clearly characterized by a high level of uncertainty. The development of risk models following this approach is tightly related to the way these uncertainties are taken into consideration. There can be many sources of uncertainty within the risk modelling context, nevertheless a widely accepted classification divides these sources as either *aleatory* or *epistemic*.

The aleatory uncertainty is related to the randomness of the phenomenon. For instance, in an earthquake, elements related to the occurrence and ground motion variability are considered as aleatory. On the other hand, epistemic uncertainty is caused by the lack of knowledge and is usually referred to the lack of data, or poor quality of such information. The main difference between the aleatory and epistemic uncertainty relates to the possibility of reduction. For the former, one does not foresee the possibility for reduction, while for the latter gathering of more data or usage of auxiliary variables can help in reducing the level of uncertainty. In a risk process the proper distinction of uncertainty depends on the circumstances and is considered as of the utmost importance, since it would help in reducing such levels of uncertainty in short- term periods (Kiureghian & Ditlevsen 2009).

5.1.1 Generalized steps in the Quantitative Risk Assessment

In the probabilistic/stochastic approach losses are calculated based on thousands of scenarios. As mentioned, the output of each scenario is then used to develop risk curves. To better understand how risk levels in terms of economic loss are defined for each of the scenarios the generalized steps are followed by simplified examples for the case of a seismic event.

Beforehand, based on the already explained concept of risk each of its constituting components can be quantified as follows:

Temporal probability P_T of a certain hazard scenario represents the probability that the parameters which define the hazard will exceed certain levels within a specified timeframe. The return period (RP) or annual probability of exceedance (p) can be used to characterize this timeframe, while the physical parameters are a function of the hazard.

Spatial probability P_S relates to the possibility that a defined location is affected by a certain hazard. The combination of P_s and P_T gives the hazard (H) component of risk in the form of *hazard maps*.

Elements at risk represent the quantification of the physical elements including; the number of people, buildings, land surfaces, monetary values and infrastructure elements that are exposed to a particular natural hazard. Quantification involves not only the specific number of exposed elements, but it also gives the amount of data gathered for each of the elements, which directly impacts the results of the process.

Vulnerability of the elements at risk represents the probability that building damage, or that of any other exposed physical element will exceed certain levels as a result of the hazardous event. Vulnerability levels are defined based on detailed analysis of the characteristic of each exposed element. In quantitative approaches such information is given in the form of *vulnerability curves* for different pre-defined typologies.

The product of each of the aforementioned components would give the risk for a single hazard scenario. The sum for all of the scenarios, which is represented by the area under the developed risk curve would give the expected losses in a year which are averaged over many years and linked with the return periods of specific hazard with specific intensity.

Step 1- Hazard Modelling

For the hazard modelling probability distributions are mainly developed based on past historical events. The refinement of such distributions is based on scientific principles and a good understanding of the behavior of natural events. For the seismic event the location of potential future events (P_S) is done based on direct observation and measurements, which helps to define faults and seismic sources. Then, attenuation laws are applied to see how the ground motion will vary with distance and therefore determine the geographical extent. The frequency of occurrence (P_T), which is tightly related to the location, in general, represents the most important aspect of the hazard modelling process since the loss is directly related to this value (Cummins, 2005). The aspects of frequency with those of the magnitude are related to one another by using the well-known Gutenberg-Ritcher law. According to which the modeling of such relationship is given by the following equation (Kramer, 1996):

$$\log(\lambda_m) = a\text{-}bm \qquad (5.1)$$

where, λ_m is the mean annual rate of exceedance of magnitude *m*

10^a represents the mean yearly number of earthquakes of magnitude greater than or equal to zero

b gives the rate at which λ_m decreases as the magnitude increases

Taking into consideration these concepts, the example includes three earthquake scenarios with different annual probability of exceedance, therefore three different return periods.

In the first scenario there is a 2% probability of exceedance with an excepted peak ground acceleration (pga) of 0.12g, the second scenario has a 1% probability of exceedance with an expected *pga* of 0.2g and the third scenario a 0.1% probability of exceedance with a *pga* 0.35g. The results are plotted in a graph which is a simplified example of how a *hazard curve* is developed.

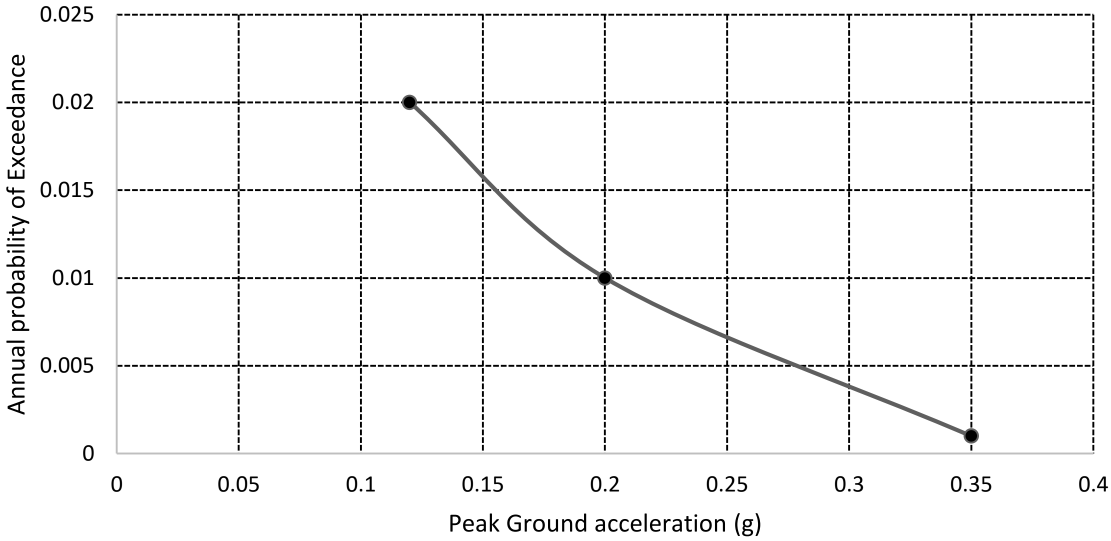


Figure 5.2 Seismic hazard curve

Step 2- Elements at risk and exposure analysis

The second step relates to the building stock inventory. Theoretically the information is given in an updatable database and it includes information related to the number of properties, their characteristics in terms of occupancy, function, structural configuration, physical accessibility, replacement cost etc. On- site inspection is a fundamental part to obtain a complete database which can be used in the vulnerability model.

For the simplified example, three general building typologies are used. Each typology is named as *Type 1*, *Type 2* and *Type 3*. Detailed information regarding the conditions for this typological division will not be analyzed as it is not important for the purpose of this example. It is considered that Type 3 buildings are the most vulnerable and Type 1 the least vulnerable (as it will be shown in the vulnerability module). From the database it is considered that replacement cost for Type 1 buildings is 300000€, for Type 2 100000€ and for Type 3 70000€.

Step 3- Vulnerability Analysis

The aim of this step is the development of the vulnerability curve which gives the level of damage expected for different levels of severity (in this case the peak ground acceleration). In probabilistic methods advanced techniques provide fairly accurate results by generating empirical, analytical or hybrid curves. The curve type is a function of the collected data. For instance, an empirical curve is based on observed earthquake damage data, while an analytical curve is based on analytically simulated damage data and hybrid curves are a combination of the above sources. The application of such methods is most of the times impractical since either the information is missing or there is not a satisfactory level of detail.

To account for this, many analyses are based on the building stock by grouping buildings or infrastructural elements in classes based on the characteristics. Each of the building classes is then analyzed and the response is applied to any other building that belongs to this class assuming that the typical buildings are selected carefully to avoid any source of bias.

For the pre-defined typologies in the second step hypothetical vulnerability curves are generated as shown in the figure below.

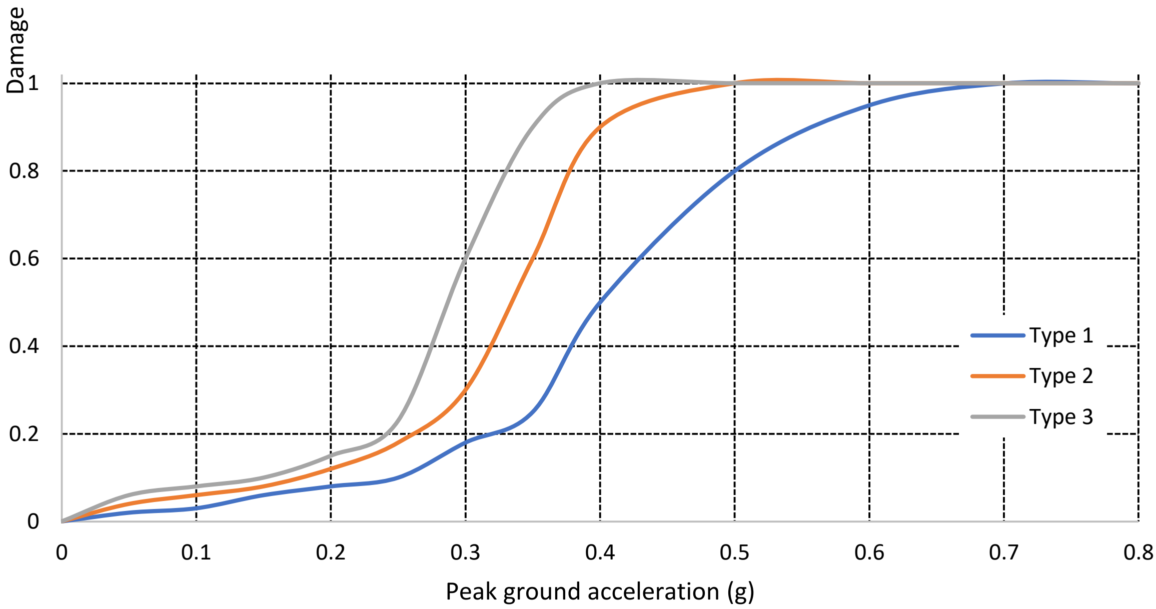


Figure 5.3 Vulnerability curves for the defined building typologies

Step 4- Loss Estimation

For this example, the loss is estimated in terms of replacement cost, but often in financial terms the loss is given in terms of *loss ratio* which is the ratio of repair cost to that of replacement cost. This ratio for highly vulnerable object under strong earthquake is equal to 1, or in specific cases greater to 1, meaning that is better to re-build rather than repair.

The loss is calculated as the product of vulnerability levels to the estimated replacement cost given in the second step, after that the loss is then aggregated for all the affected typologies for the same levels of expected peak ground acceleration. The information is summarized in the table below:

Table 5.1 Calculation of the Aggregate Loss

	Annual Probability	Vulnerability	Replacement Cost	Loss	Aggregate Loss
Type 1	0.02	0.035	300000	10500	22950
Type 2	0.02	0.065	100000	6500	
Type 3	0.02	0.085	70000	5950	
Type 1	0.01	0.08	300000	24000	46500
Type 2	0.01	0.12	100000	12000	
Type 3	0.01	0.15	70000	10500	
Type 1	0.001	0.25	300000	75000	198000
Type 2	0.001	0.6	100000	60000	
Type 3	0.001	0.9	70000	63000	

Step 5- Risk Analysis

In the final step of the analysis the aggregated losses against each of the scenarios are plotted to create the risk curve. The area below the curve represents the Average Annual Losses (AAL). Mathematically it is the integration of all losses with regard to all probabilities.

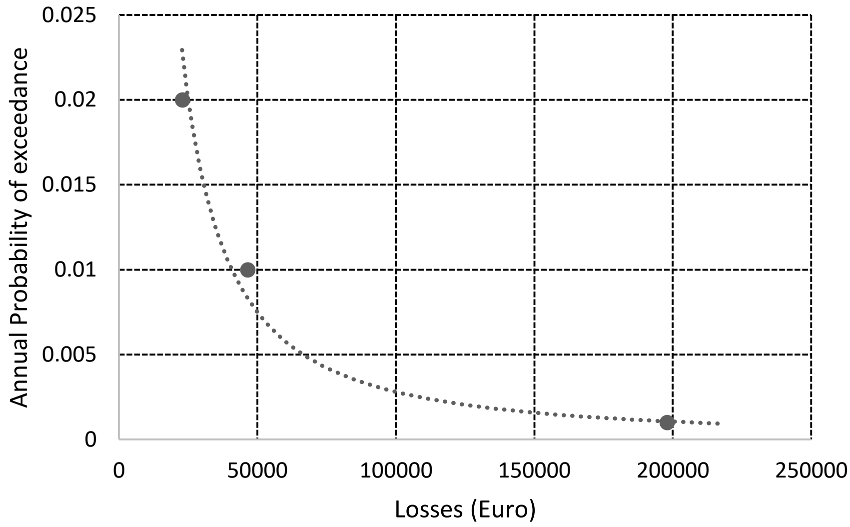


Figure 5.4 Development of the risk curve

5.2 The Deterministic Approach

The deterministic approach considers the consequences of a defined event and is based in the concept of *allowable threat*. The main aim is that of proving if the consequences are either manageable or not. The main difference with the probabilistic approach is that in the deterministic approach there is no integration of probability concepts to account for the aforementioned uncertainties. Another difference is that probabilistic approach attempts to capture all possible outcomes associated with relevant probabilities while deterministic approach only works on predefined scenarios that may not always be captured within this deterministic event. Nevertheless, such approach is considered as a good alternative to stochastic models when there is lack of data, lack of capacities or any other restriction.

Since this approach works only on a certain predefined number of potential events it is not fully reliable. Nonetheless, the practical aspects combined with a quick evaluation time make this approach preferable to other more sophisticated methods specially for prescreening processes. Another advantage relates to the fact that if the output is presented properly, it can be understandable and clear not only for risk specialists but even for the affected communities, thus making such approach applicable for several decision-making issues.

5.3 Risk Assessment techniques and tools

Risk assessment process may have a varying degree of detail as a function of the final objective and the availability of relevant data. Thus, the methods, techniques and tools used during the process are variable; from simple preliminary methods up to more complex ones. The techniques should be selected based on a number of factors including (ISO 31010, 2009):

a. *The objective of the study*. For a more specific study detailed results are needed, while for general or comparative studies a simplified approach is sufficient.
b. *Decision- making needs*. There are cases when for decision- making purposes a high level of detail is needed, while in others more simplified approaches with less details are preferable.
c. *The potential magnitude of the consequences*. The chosen technique should reflect the initial perception of the consequences.
d. *The level of expertise and other additional resources*. When there is lack of expertise it is preferable to use correct simplified methods rather than advanced and complex procedures poorly done, as long as the objective of the assessment is met.
e. *Data availability*. Advanced techniques require more information than simplified ones.
f. *The need for future updates*. As risk is variable in time future needs may require updates and some techniques are more updatable than others.
g. *Additional legal requirement*.

Focusing on risk analysis the methods can be **qualitative**, **quantitative** or **semi-quantitative**.

In the *qualitative assessment* the output is defined qualitatively using significance levels like "high", "medium" or "low". Such risk levels are determined based on expert's opinions on the consequences and likelihood and are subject to subjective thinking.

In the *quantitative analysis* consequences and likelihood are expressed in numerical terms using probabilistic relationship. Therefore, the risk levels are also expressed numerically and the approach is objective justified by measurable results.

Semi-quantitative analysis categorizes risk using numerical rating scales also known as comparative scores. This analysis is characterized by the process of scoring/scaling and weighting. The scores given to elements representing likelihood and consequences are combined to give a final risk score. The semi-quantitative approach is considered as hybrid since it has quantitative and qualitative aspects and the output can serve as a strong starting point for identification of elements that might require additional analytical effort.

ISO 31010 lists 31 techniques to be used in the entire process of assessing risk (identification, analysis and evaluation) where among these techniques the most relevant in the context of natural hazards are summarized in the following table. Furthermore, each of the techniques is briefly described and classified based on the nature of the output:

Table 5.2 List of the main Risk Assessment Techniques and Tools (based on ISO 31010, 2009)

Tools and techniques	Quantitative	Qualitative	Semi- Quantitative
Preliminary Hazard Analysis (PHA)		x	
Delphi Technique		x	
FMEA+ FMECA	x	x	x
Fault Tree Analysis	x	x	
Event Tree Analysis	x		
Monte- Carlo Analysis	x		
Bayesian Analysis	x		
Risk Indices			x
Risk Matrix		x	x
Multi-criteria Decision Analysis			x

5.3.1 Preliminary Hazard Analysis (PHA)

The Preliminary Hazard Analysis is a simple method of analysis with the main objective that of *identifying* hazards associated with their causes and the severity of their consequences. The process takes into consideration in a qualitative way the elements related to the hazard, the event that might cause the hazard, specified hazardous situation, specification of the failure, specification of the consequences of such failure and potential measures. The information produced using PHA may be presented using either tables or tree diagrams. The possibility of usage by non-system experts, or the application in cases where the information is limited are some of the main advantages, while the main limitation relates to the fact that a PHA provides a preliminary information and does not give detailed results on risks and their prevention.

5.3.2 Delphi Technique

The Delphi method is a procedure to obtain reliable opinion from a panel of experts based on multiple rounds of questionnaires (ISO 31010, 2009 & Twin, 2022). The essential feature of this technique is that the opinion of the experts is expressed individually and anonymously. Such technique is useful in matters of risk assessment since the independent opinion of the experts provides good information which can later be used to assess the most and least important components in terms of severity and consequences.

The main advantage is the aggregation of different anonymous opinions that are free of any repercussion, also all views have an equal weight. On the other hand, the main limitation is that the procedure is time- consuming and the opinions need to be clear in writing to avoid any misunderstanding.

5.3.3 Failure Mode and Effects Analysis (FMEA) and Failure Mode, Effects and Criticality Analysis (FMECA)

FMEA is a technique used to identify the possible ways in which components, systems or processes might not fulfill the intent. Such method was firstly used in aerospace and electronics industries, but now has a wide range of usage including the prediction of failure and consequences from a natural or technological event in the built environment. In general, FMEA identifies all potential failure modes, the effects of these failures on the system and the possibilities to avoid or mitigate such effects.

FMECA is an extension of FMEA in which the consequences of failure events can be ranked according to their importance and criticality. The criticality is defined by combining mainly qualitative information related to the frequency of failure and consequence in the form of a matrix, but it can also have quantitative aspects. Some of the advantages of these combined methods include; the systematic and rigorous process, application to a wide range of system types, the possibility to provide an important input to monitoring processes by highlighting key elements to be monitored.

The main limitations include the consideration of single failure modes and not a combination of them and can be time- consuming unless controlled properly.

5.3.4 Fault Tree Analysis (FTA)

Fault Tree Analysis is a logic diagram that identifies and analyses factors that contribute to a certain specified undesired event (failure) known as the “top event”. The factors that cause such event can be identified and organized in a logical manner and visually represented in the form of a tree diagram. In the top of the tree diagram stands the “top event” while at the extremities stand the “basic events” which represent factors that cannot be dissected further. Between the top and basic event stand the “intermediate events”. The logical relationship between the events is represented through the “logical gates”. This method can be used both qualitatively and quantitatively. In the qualitative approach potential causes and paths to a failure are identified while for the case of quantitative approach the probability of the “top event” starting from the probabilities of “basic events” is calculated.

The main advantage of a FTA is the systematic and flexible approach which allows the analysis of several factors and at the same time is easy to read and understand. Detailed knowledge requirement, the uncertainties in the probabilities of “basic events” and the static nature (not being time- dependent) represent some of the limitations of such analysis.

5.3.5 Event Tree Analysis (ETA)

Event Tree Analysis is a representation of the logical order of sequences of an event leading to some condition of interest. The development of an ETA starts with the selection of the initiating event that can be a power failure, a hazardous event etc. This event is followed by all possible outcomes and for each one of these outcomes lines are drawn to represent success or failure. In quantitative terms the probabilities of each outcome are expressed as conditional probabilities therefore each path in the event tree represents the probability that all of the events in that path will occur. The graphical representation and consideration of domino effects are some of the advantages of this technique, while the risk of having a complex tree and the difficulty to identify all consequences represent some setbacks.

The complementary nature of FTA and ETA represents often a source of confusion, but if the event tree is drawn from left to right the FTA is drawn up to down and also the aim of the ETA is to predict consequences with the aim of mitigating rather than finding the consequences with the aim of preventing them as it is the case of FTA.

5.3.6 Monte Carlo Simulation

When a problem is characterized by a great number of uncertainties it results in complex systems whose solution is difficult to be achieved using analytical techniques. To overcome these difficulties, a number of simulations are performed using as input a certain number of random variables with distributions according to the level of uncertainties. In general, the process starts with the definition of the algorithm which represents the system and its behavior, this model is run multiple times based on the random variables and for each simulation an output is provided. The relationship between inputs and outputs in such models provide clarification regarding the main factors that can be targeted to achieve a certain situation or goal. Some of the main strengths of this technique include the fact that the generated performance functions that give the relationship between the variables serving as inputs with the outputs are straightforward and clear. In addition, such method provides means to control and measure the accuracy of the results. The main limitation relates to the strong mathematical knowledge of the user since it is fundamental to apply a valid distribution of the variables to represent the uncertainties.

5.3.7 Bayesian Analysis and Networks

The Bayesian Analysis is an analysis that generates from what is known as Bayes Theorem that determines conditional probability. The premise is that an existing information, known as the Prior whose probability of occurrence is already known can be used to obtain probabilities of an outcome, known as posterior as the formula shows (Kjærulff & Madsen, 2013):

$$P(X|Y) = \frac{P(Y|X)P(X)}{P(Y)} \qquad 5.2$$

P(X|Y)- Posterior probability of X given Y

P(Y|X)- Posterior probability of Y given X (likelihood)

P(X)- Probability of A being true (knowledge)

P(Y)- probability of B being true (marginalization)

On the other hand, a Bayesian Network can be described as:

"…an acyclic directed graph (DAG) which defines a factorization of a joint probability distribution over the variables that are represented by the nodes of the DAG, where the factorization is given by the directed links of the DAG".

Simplified, the nodes represent the events and are generally classified as Parent Node and Child Node, the arrows represent the relationship between the nodes and each of the nodes is associated with a Conditional Probability Table (CPT). The following example is a simple Bayesian Network where **A** is the Parent Node for **D** and **C**, **B** is the Parent Node for **C** and **C** is the Child Node of **B** and **A**, but is a Parent Node for **D**.

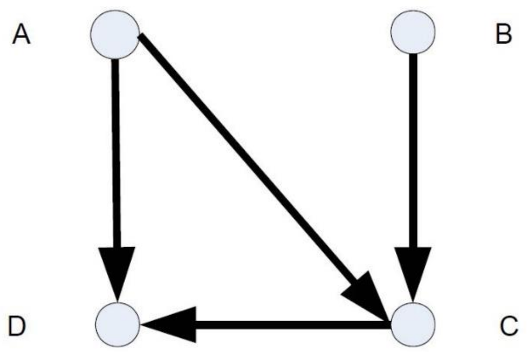


Figure 5.5 Example of a Bayesian Network (ISO 31010, 2009)

Some strengths of this technique include the necessity of knowledge only for the prior events, application of only one rule (Bayes' Theorem) and serves as a mechanism for integrating subjective beliefs in a certain problem. While the main limitation relates with the fact that the definition of all nodes and interaction between them is often complex and the definition of a CPT is challenging.

5.3.8 Risk Matrix

Risk matrix represents a qualitative tool which is used to combine consequences and likelihood in order to produce a certain level of risk. The matrix is structured based on the context in which it is applied. The primary objective of this tool is to rank and categorize risk, sources of risk and define risk treatments based on the level of defined risk. The matrix is often used to define if a given risk is acceptable or not acceptable based on the location in the matrix. The input for such tool is the customized scales for consequence and likelihood (probability) which then serve as axis for the final matrix. Each combination of the levels of severity and likelihood is represented by a cell in the matrix and the number of points representing likelihood and consequence which will define the matrix are a function of the problem at hand and may vary based on the information availability.

In ranking the risk, the first step is to describe the consequences and to define the relevant probability of occurrence, then each point of the matrix that gives the risk is ranked with quantitative scales or qualitative scales accompanied by proper description. In addition, the defined level of risk can be associated with several decision-making proposals that aim in reducing and treating the risk.

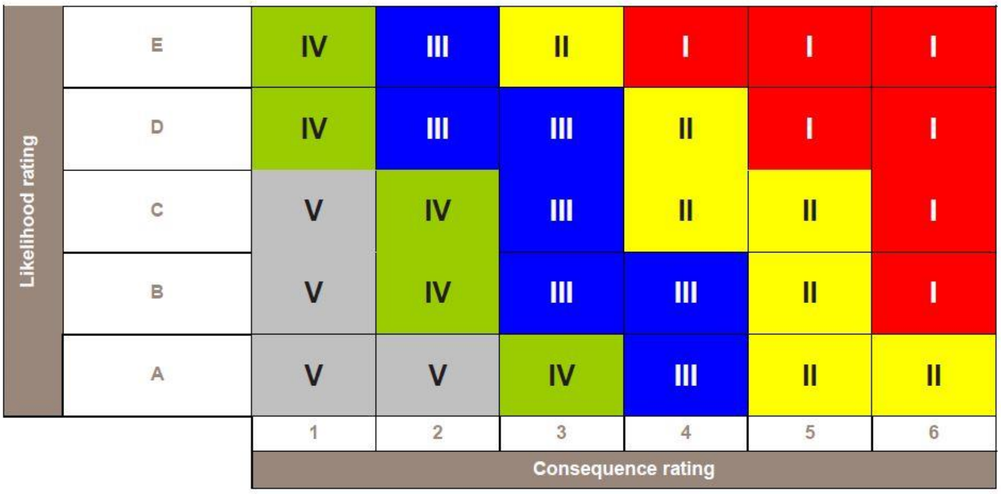


Figure 5.6 Example of a risk matrix (ISO 31010, 2009)

Regarding the two remaining methods, thus the Risk Indices and Multi- Criteria Decision Analysis, the theoretical analysis will be detailed below (5.4 and 5.5) as they represent the theoretical core for the methodology proposed in this research.

5.4 Risk Indices as a Semi- Quantitative approach

Risk Index is an approach in which the risk and its constituting elements are derived through a scoring process using ordinal scales. Such approach is more rigorous than a qualitative approach, but is not considered as a purely quantitative approach since the risk is categorized by comparative scores rather than explicit probabilistic terms. Therefore, such approach is categorized as a *semi- quantitative*.

Risk Indices are used in situations where the lack of data makes it difficult to quantify the components of the risk and also when the assessment is carried out in large areas. The input is derived from a detailed analysis of the system thus, the assessment of risk in terms of indices should be preceded by a detailed analysis and a good understanding of the sources of risk. In this stage of the process additional tools such as fault tree or event tree analysis (explained above) can be used to structure the problem and represent the relationship between each component of risk and each of the indicators selected to represent such components at different levels.

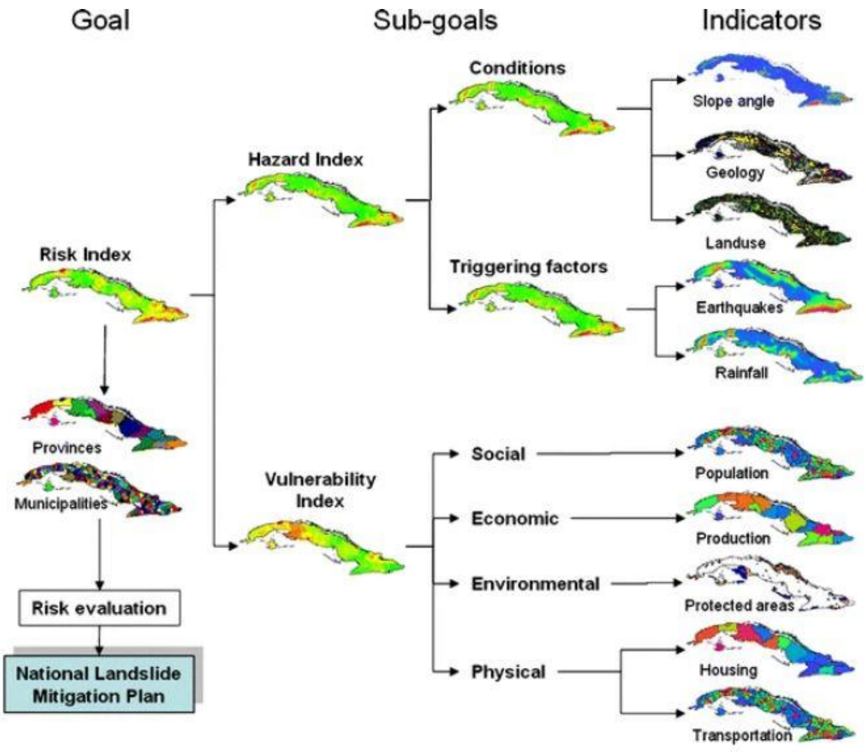


Figure 5.7 Landslide Risk Assessment Model (Abella & Van Westen, 2007)

For instance, the above scheme is the model proposed by (Abella & Van Westen, 2007) to evaluate the landslide risk in a national level. The model has a structure composed by four levels divided into indicators and sub-goals to converge into a single risk index. The number of levels or indicators selected to represent the entire model is variable and depends firstly on the level of detail required and also on the complexity of the problem itself. The possibility to rank and easily compare different risks and the integration of multiple factors of a different nature into the model as dimensionless units to account for a holistic approach are some of the main advantages of this method. The main limitation of this method is the need for validation to avoid potential misinterpretations of the output.

Since the objective is to put into a single model different indicators of different nature and of different units the challenge is to properly define the relationship between the real indicator and the scaled one through different relationship (linear, logarithmic, or any other form).

5.5 Spatial Multi-Criteria Evaluation

A rational decision in a decision- making process is based on several criteria, which represent measurable attributes of the alternatives being considered. In most situations decisions are taken on a basis of a variety of criteria. The process through which the criteria are combined to give alternatives is known as multi- criteria evaluation (Eastman, J.R, 2005).

In the field of disaster risk reduction and natural hazards, the information is often given in a spatial way through maps. In cases where the input is a number of geographical data that can be used for choosing alternatives and making decisions the process is known as Spatial Multi- Criteria Evaluation (SMCE). Spatial Multi- Criteria Evaluation is considered as a complementary method to the already existing approaches for qualitative and quantitative risk analysis and zoning. For instance, as it is the case of this research, indices at a local scale are combined with the SMCE to provide a single risk value that can be used for decision-making purposes or preliminary evaluations.

Based on the relevant literature (Eastman, J.R, 2005; Sinha, Priyanka & Joshi, 2014 and Patel, M. R. et al., 2017) the procedure for converting various parameters into a single risk index that can be later used for decision-making processes goes through four general steps as given below:

Step 1- The structure of the decision problem

Step 2- Standardization

Step 3- Weighting Process (Prioritization)

Step 4- Aggregation

In line with the purpose and objectives of this research, these four general steps are analyzed and represented in more detail, resulting therefore in a structure including nine steps from the input up to the decision-making as shown in the scheme below:

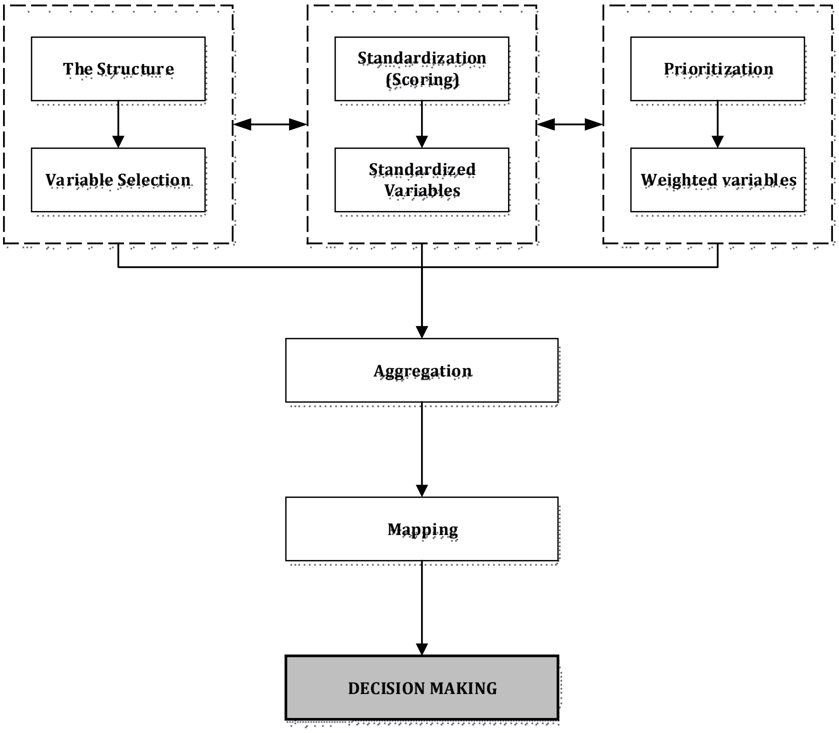


Figure 5.8 The structure of the proposed methodology based on SMCE (the author)

5.5.1 Standardization and Value Functions

It has already been pointed out that decision-making processes require the integration of a number of variables of different nature, the combination of which provides alternatives. Based on the alternatives, decisions are made to choose the most acceptable one in terms of objectives and feasibility.

The integration of numerous variables in such processes to define the worst and/or the best scenarios requires an analysis in which these variables are compared and combined to one another. Making two or more variables comparable requires a scaling or standardization of them, thus resulting at the same unitless scale.

The process of switching from a variable of a certain nature to unified variables is defined as ***standardization process***. Relevant literature review has shown the use of different terminologies for the same concept; many authors define it as ***scaling*** while others define it as ***normalization*** or ***standardization*** as mentioned above. Nevertheless, no matter the term used the meaning is the same as the one explained. In this research the term ***standardization*** is going to be used.

Based on the nature of the variables and the problem in hand the standardization process can be achieved using either mathematical equations or standardization tables. The first approach is mostly used when the variables have a measurable numeric nature, while the second one when the information is more qualitative. However, such qualitative information can also be converted in unitless scale using equations too.

The mathematical rigor of equations makes them preferable to judge for the selection of alternatives, but on the other hand their interpretation is complicated. Thus, such equations are often represented in form of function graphs, widely known as **value functions**.

(Beinat, 2012) defines value functions as:

> *"…mathematical representation of human judgements."*

explaining that this function translates performances of the alternatives into value score, which on the other hand represents the degree to which several decisions are matched. After the application of such functions all the variables used for decision are analyzed for their meaning and impact in the decision rather than analyzed as explicit numerical values or qualitative measures.

A key component in the decision-making process is the accurate determination of value functions. Once a value function has been defined, the results for a given set of choices can be calculated directly. Since value functions represent a preference there is a need of proper and clear evaluation instead of just the graphical representation of such functions. In their work *(Eisenführ, Weber and Langer, 2010)* explain some of the most used methods for the determination of value functions*:*

The direct ranking method

This method is considered one of easiest ways to determine a value function. In the first step the ranges of the variables (parameters) are defined. This range, given by a maximum and minimum value represent the domain for the parameter. In the second step, all the values of the parameter/criterion at hand are listed with the respect to the decision maker's preference, thus from worst to best. The third step represents a direct evaluation of each of the parameter's value and then this relationship is normalized in the interval from 0-1 and plotted (fourth step).

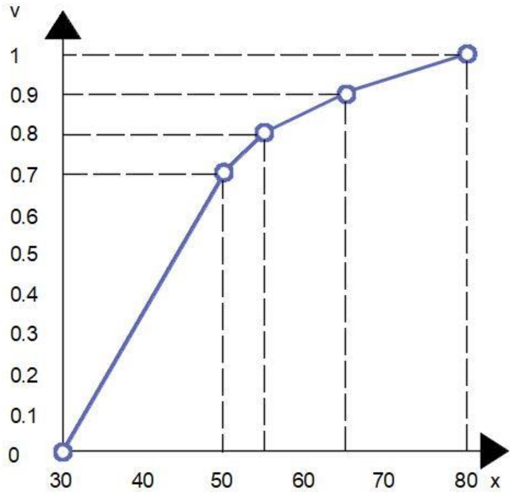


Figure 5.9 Definition of a value function using the direct ranking method (adapted from Eisenführ et al., 2010)

The difference standard sequence technique

The method is based in generating equal value differences. In the first step the worst relevant value (x_{min}) for the parameter is determined and the outcome preference of this value is considered 0 (representing the worst case, or the least preferable solution by a decision-making point of view). Secondly, a unit is defined representing approximately 1/5 of the total range of parameter's value which is added to the worst relevant value giving a new parameter value. Such difference will impact the preference (outcome) in a certain level. The step is repeated in sequence x_{min}, x_1, x_2,...x_j, such as the rate of change in preference is the same for each variable change until the maximum preferred value of 1 is achieved. In the third step the values are normalized and plotted in a graph.

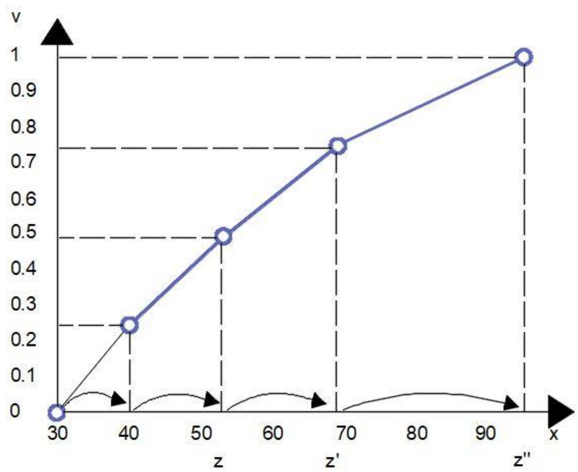


Figure 5.10 Definition of a value function using difference standard sequence (adapted from Eisenführ et al., 2010)

The bisection method

In the bisection method firstly the range of parameters is defined x_{min} and x_{max}. Then the value of the parameter that bisects the interval [x_{min}; x_{max}] is specified and named $x_{0.5}$, thus the change from x_{min} to $x_{0.5}$ is the same as $x_{0.5}$ to x_{max}. The corresponding preference value for such parameter is 0.5. In the third step the new intervals [x_{min}; $x_{0.5}$] and [$x_{0.5}$; x_{max}] are bisected and denoted as $x_{0.25}$ and $x_{0.75}$ with corresponding values of 0.25 and 0.75. In the final step the graph is drawn based on these specified points.

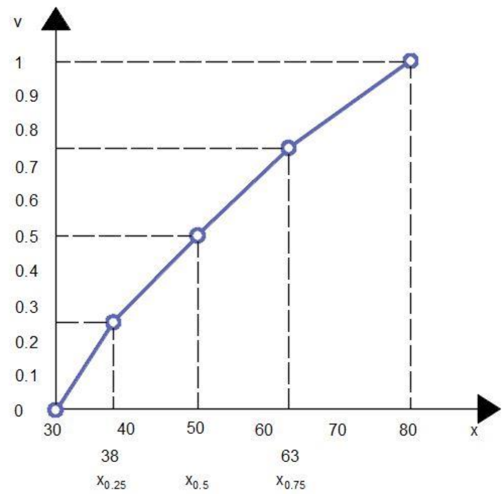


Figure 5.11 Definition of a value function using the bisection method (adapted from Eisenführ et al., 2010)

Literature provides numerous other techniques and formulas that can be used to develop such functions.

According to (Alarcon, et al., 2011):

> *"... the value function objectivizes the subjectivity for a specific variable and viewpoint"*

Taking into consideration this and difficulties in application due to the lack of real physical sense the authors outline a simplified procedure of four steps based on the MIVES model as follows:

Step 1- Definition of the tendency

Step 2- Definition of the range

Step 3- Definition of the shape of the value function based on the studied parameter

Step 4- Definition of the equation or the mathematical expression of the value function

Each of the steps have a standard procedure that will be detailed below.

Definition of the tendency of a value function

Depending on the nature of the indicator (criterion) the value function can have either an *increasing* or a *decreasing* tendency. An increasing function reflects an increase in the level of satisfaction of the decision maker with the increase of the level of the indicator that has an impact in this decision. On the other hand, a decreasing value function shows that an increase in the indicator results in a decrease in the level of satisfaction. Specific cases are those when value functions have a *mixed* tendency; thus, the functions have an increasing or decreasing tendency up to a certain level of the criterion after which the relationship is inverse. Such functions require the level of the indicator for which this tendency changes.

Definition of the range

The range consists in defining the points which have the minimum and maximum level of satisfaction from the decision- maker's point of view. If using a scale from 0 to 1, the point of minimum satisfaction would give a value of 0, while the maximum would give a value of 1 or vice versa. It is important to notice that this range represent limits in the satisfaction level only, not in the entire range of values for the considered criterion. Thus, there might be values of the criterion which are not considered because they are outside the defined satisfaction limits.

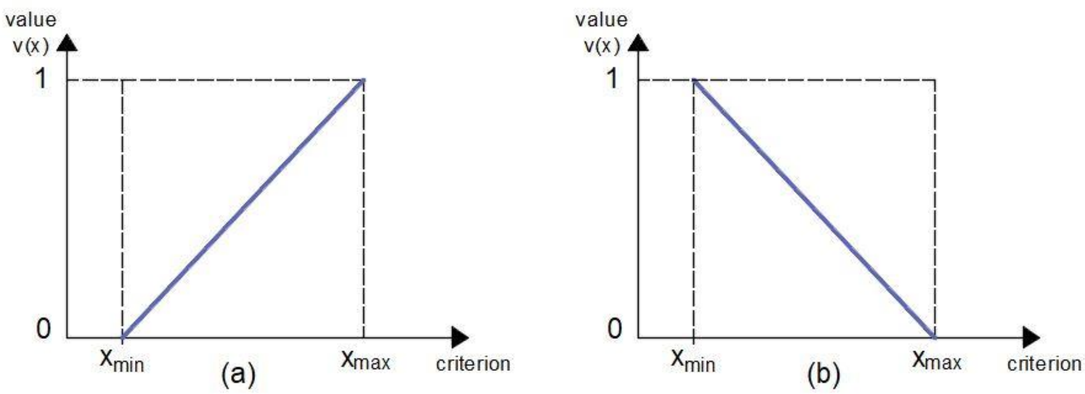


Figure 5.12 Increasing tendency (a) and decreasing tendency (b) of a value function

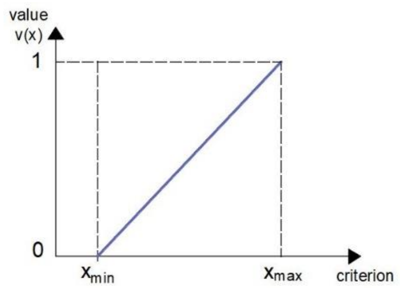
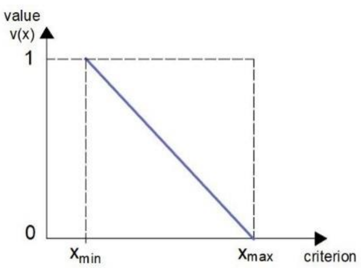
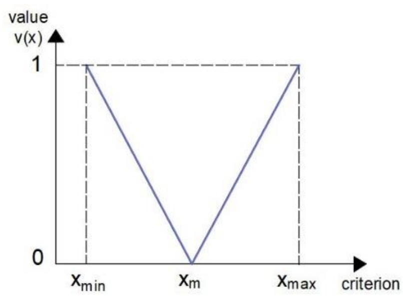
Shape of the value function and the mathematical models

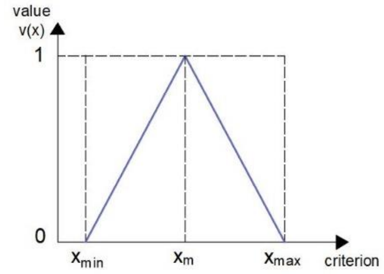
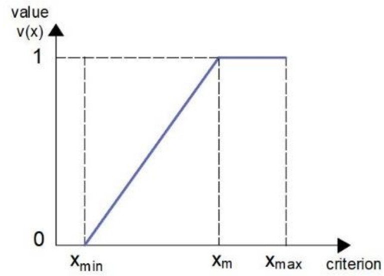
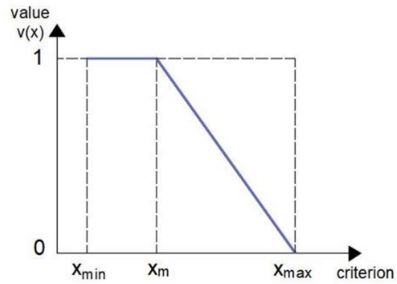
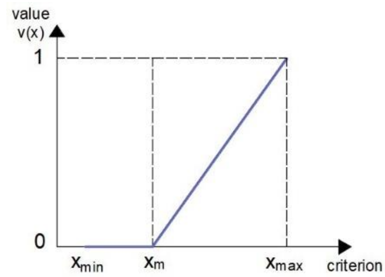
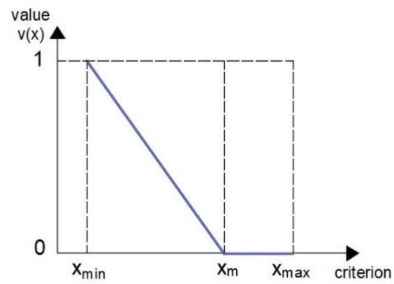
The next step in the generation of value functions is the definition of the shape that will connect the points within the defined range. Literature suggests several types of functions that can be used for decision-making. For the purpose of this research based on (Alarcon, et al., 2011) and (Rezaei, 2018) the value functions are classified into two groups *linear* and *exponential*. Both linear and exponential value functions following the tendency (Step 1) might be classified as *monotonic* when the tendency is always increasing or decreasing or *non- monotonic* when it has a different shape (mixed). Each of the value functions will be detailed in terms of shape and mathematical model used for the generation of such value functions.

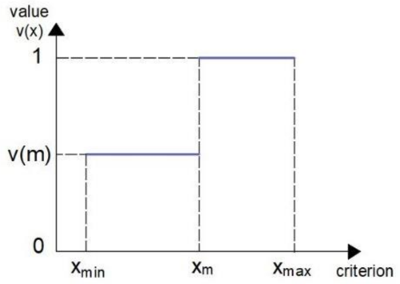
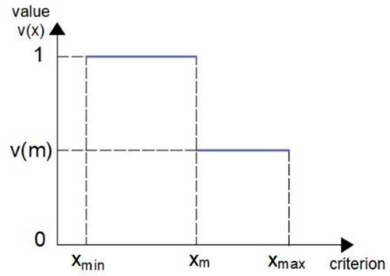
Linear functions

A linear function reflects a steady and constant increase or decrease in the level of satisfaction produced by the alternatives. Throughout the range, there is a proportionate relationship meaning that the rate of change is constant. Table 5.3 summarizes the types of linear function based on the tendency and their nature (monotonic and non- monotonic) together with the corresponding piecewise equations.

Table 5.3 Linear Value Functions (adapted from Rezaei, 2018)

Function	Nature	Type	Graph	Piecewise Equation
Linear	Monotonic	Increasing		$v(i)=\begin{cases}\dfrac{x_i-x_{min}}{x_{max}-x_{min}}, \\ 0\end{cases}$
		Decreasing		$v(i)=\begin{cases}\dfrac{x_{max}-x_i}{x_{max}-x_{min}}, \\ 0\end{cases}$
		V- Shape		$v(i)=\begin{cases}\dfrac{x_m-x_i}{x_m-x_{min}}, x_{min}\le x_i\le x_m \\ \dfrac{x_i-x_m}{x_{max}-x_m}, x_m\le x_i\le x_{max} \\ 0\end{cases}$

<table>
<tr>
<td rowspan="5"></td>
<td rowspan="5">Non-Monotonic</td>
<td>Inverted V-Shape</td>
<td>
</td>
<td>$v(i) = \begin{cases} \frac{x_i - x_{max}}{x_m - x_{min}}, x_{min} \le x_i \le x_m \\ \frac{x_{max} - x_i}{x_{max} - x_m}, x_m \le x_i \le x_{max} \\ 0 \end{cases}$</td>
</tr>
<tr>
<td>Increase Level</td>
<td>
</td>
<td>$v(i) = \begin{cases} \frac{x_i - x_{min}}{x_m - x_{min}}, x_{min} \le x_i \le x_m \\ 1, x_m \le x_i \le x_{max} \\ 0 \end{cases}$</td>
</tr>
<tr>
<td>Level Decrease</td>
<td>
</td>
<td>$v(i) = \begin{cases} 1, x_{min} \le x_i \le x_m \\ \frac{x_{max} - x_i}{x_{max} - x_m}, x_m \le x_i \le x_{max} \\ 0 \end{cases}$</td>
</tr>
<tr>
<td>Level Increase</td>
<td>
</td>
<td>$v(i) = \begin{cases} 0, x_{min} \le x_i \le x_m \\ \frac{x_i - x_m}{x_{max} - x_m}, x_m \le x_i \le x_{max} \\ 0 \end{cases}$</td>
</tr>
<tr>
<td>Decrease Level</td>
<td>
</td>
<td>$v(i) = \begin{cases} \frac{x_m - x_i}{x_m - x_{min}}, x_{min} \le x_i \le x_m \\ 0, x_m \le x_i \le x_{max} \\ 0 \end{cases}$</td>
</tr>
</table>

		Increasing Stepwise		$v(i)=\begin{cases} v_{(m)}, x_{min} \le x_i \le x_m \\ 1, x_m \le x_i \le x_{max} \\ 0 \end{cases}$
		Decreasing stepwise		$v(i)=\begin{cases} 1, x_{min} \le x_i \le x_m \\ v_{(m)}, x_m \le x_i \le x_{max} \\ 0 \end{cases}$

In addition to the piecewise equations for the linear monotonic value functions, the general equation proposed by MIVES can be used

$$V_{ind} = B \times \left[1 - e^{-K\left(\frac{\left|X - S_{min}\right|}{C}\right)^{P}} \right] \tag{5.3}$$

where

V_{ind}- value of indicator evaluated (same as $v_{(i)}$)

B- factor that allows the function to remain within the defined range (0-1), calculated as:

$$B = \frac{1}{\left[1 - e^{-K\left(\frac{\left|S_{max} - S_{min}\right|}{C}\right)^{P}} \right]} \tag{5.4}$$

S_{min}- the point of minimum satisfaction (same as x_{min})

S_{max}- the point of maximum satisfaction (same as x_{max})

X- represent the point in x-axis that generates V_{ind} (same as x_i)

P- defines the shape of the curve. *For P≈1 the function is linear*

C- parameter that defines the point in x-axis corresponding to the point of inflection (for P>1)- *for linear increasing or decreasing function C≈X_{min}*

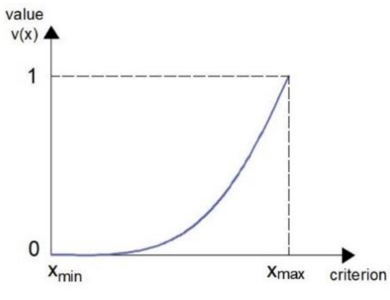
K- parameter that defines the value in y-axis at point C- *for linear increasing or decreasing function K≈0*

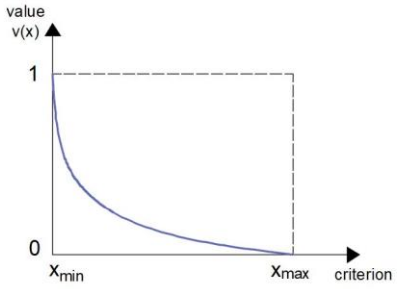
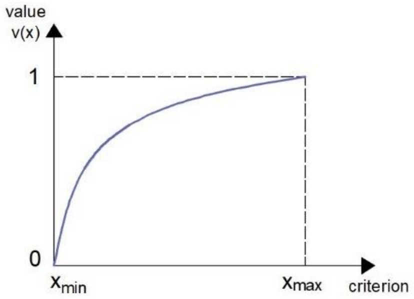
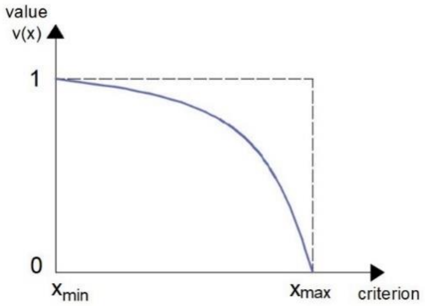
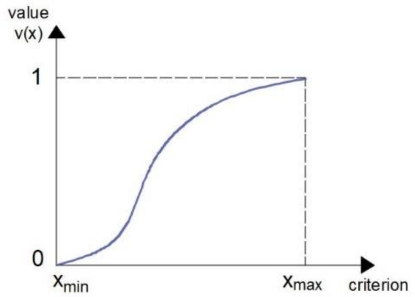
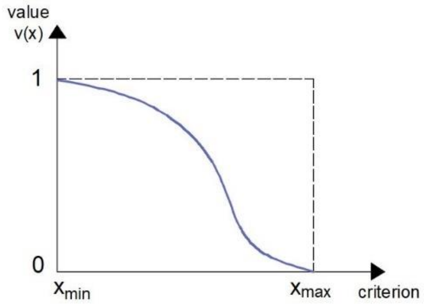
For the purpose of this research the main equation that will be used to generate value functions is Eq. 5.3. In the cases, when possible non- monotonic linear value functions might be required, the pairwise equations of Tab. 5.3 will be used since Eq. 5.3 does not cover such functions.

<u>Exponential functions</u>

The exponential functions reflect change rates that are not constant, thus the rate of change near a certain value might be higher than that near another value, emphasizing that the influence of a variable (criterion) changes within the same value function. As with linear functions, the exponential functions also have monotonic and non-monotonic nature. Table 5.4 summarizes types of exponential functions based on the same criterion as for the linear functions.

Table 5.4 Exponential Value Functions (adapted from Rezaei, 2018)

Function	Nature	Type	Graph	Piecewise Equation
Exponential	Monotonic	Convex Increasing		$v(i) = \begin{cases} \dfrac{1-e^{\left[-(x_i - x_{min})/\rho\right]}}{1-e^{\left[-(x_{max} - x_{min})/\rho\right]}}, \rho < 0 \end{cases}$

		Convex Decreasing		$v(i) = \left\{ \dfrac{1 - e^{\left[-(x_{max} - x_i)/\rho\right]}}{1 - e^{\left[-(x_{max} - x_{min})/\rho\right]}} \right., \rho < 0$
		Concave Increasing		$v(i) = \left\{ \dfrac{1 - e^{\left[-(x_i - x_{min})/\rho\right]}}{1 - e^{\left[-(x_{max} - x_{min})/\rho\right]}} \right., \rho > 0$
		Concave Decreasing		$v(i) = \left\{ \dfrac{1 - e^{\left[-(x_{max} - x_i)/\rho\right]}}{1 - e^{\left[-(x_{max} - x_{min})/\rho\right]}} \right., \rho > 0$
	Non-Monotonic	Increasing S-Shape		MIVES
		Decreasing S-Shape		MIVES

For the same value functions represented in the Table 5.4 the Eq. 5.3 and 5.4 can be used, taking into consideration values of C, K and P as in the table below:

Table 5.5 Recommended values of P, K and C (adapted from Alarcon, et al., 2011)

Function	K	P	C
Increasing Convex	<0.5	>1	$x_{min} + \frac{x_{max} - x_{min}}{2} < C < x_{min}$
Increasing Concave	>0.5	<1	$x_{min} < C < x_{min} + \frac{x_{max} - x_{min}}{2}$
Increasing S-Shape	0.2/0.8	>1	$x_{min} + \frac{x_{max} - x_{min}}{5} < C < x_{min} + \left(x_{max} - x_{min}\right)\frac{4}{5}$
Decreasing Convex	<0.5	>1	$x_{max} < C < x_{max} + \frac{x_{min} - x_{max}}{2}$
Decreasing Concave	>0.5	<1	$x_{min} - \frac{x_{min} - x_{max}}{2} < C < x_{min}$
Decreasing S-Shape	0.2/0.8	>1	$x_{max} - \left(x_{max} - x_{min}\right)\frac{4}{5} < C < x_{max} - \frac{x_{max} - x_{min}}{5}$

In the generation of exponential functions using either pairwise equations or MIVES equation an important step is a verification of the shape in order to be sure that it matches the desired relationship. For instance, if using Eq. 5.3 a careful study of P, C and K is important, while if using pairwise equations such analysis must be done for the shape parameter ρ. Such verifications can be done using trial and error processes in combination with decision- makers point of view.

In conclusion, two important points regarding the development of value functions must be considered. The first one is regarding the shape and parameters of the value functions, which are both decision- maker- dependent. For instance, if one decision-maker decides to use a linear graph, another decision maker might consider an exponential graph.

Also, even if several decision- makers might use the same shape to evaluate an alternative the parameters they consider might be different (Rezaei, 2018).

5.5.2 Weighting using the Analytic Hierarchy Process

In the same way decision making involves many criteria and sub criteria to evaluate alternatives, so does the process of assessing a risk. The inclusion of several criteria into the analysis, as mentioned before, requires their comparison so that decisions are made in a proper way. In a certain analysis, decision- maker might consider that some aspects or criteria are more relevant and important than others, thus their impact in the alternative is greater. The relative importance of different criteria is otherwise known as *weight*.

In a multi- criteria decision making (MCDM) the main concern relates to the information that must be included and where such information is to be included. The best way to organize this information is to arrange it in the form of a hierarchy including relevant detail in order to represent the problem as thoroughly as possible, to identify issues and attributes that contribute to the solution and identify the participants or stakeholders. It is important to be aware that the weights of the variables included in the analysis are related to the variables of the same hierarchical level.

One of the most used techniques to assign weights is the Analytical Hierarchy Process (AHP) which is developed by (Saaty, 1980). The essence of such method is the development of what are known as *pairwise comparison matrices* at each level of the hierarchy. As stated by (Saaty, 2008), making a decision to organize priorities requires the decomposition of the general problem and the decision into the following steps:

- Problem definition and determination of the knowledge sought
- Structure of the decision from top with the main goal up to the lowest level
- Development of a set of pairwise comparison matrices for each level
- Use the results of the matrices to weight the alternatives in the same level and to obtain the overall priority.

Development of pairwise comparison matrixes

The Analytical Hierarchy Process begins with the creation of the pair-wise comparison matrix. In order to make comparisons there is the need for a scale of numbers that indicate how one element is more important than the other. The scale adopted by Saaty is represented in the following table:

Table 5.6 The scale of relative importance (adapted from Saaty, 2008)

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong Importance	Experience and judgement strongly favor one activity over another
6	Strong Plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

In the table; values 2, 4, 6 and 8 are used when compromise is needed regarding the relative importance of the elements. The pairwise comparisons are carried for all the elements considered and are arranged in a square matrix $A_{(nxn)}$, where n is the number of the elements considered. A reasonable assumption in building the matrix is that if the relative importance of an element ***i*** compared to an element ***j*** has a value of ***x*** (determined by the aforementioned table), then to maintain consistency and coherence the importance of element ***j*** with regard to ***i*** has a reciprocal value **1/x**. In the same matrix the elements of the diagonal have a value of 1.

Development of the weight vector (eigenvector)

After the completion of matrixes for each element in the same corresponding hierarchy level the definition of the weights is done by the development of the weight vector, known as *normalized principal eigenvector*. In literature and mathematical applications such vector is also known as *priority vector (w)* and is the vector of order *n* such as:

$$Aw = \lambda_{max} w \qquad (5.5)$$

where

A is the reciprocal square matrix (nxn)

W is the highest eigenvector of order n

λ is the eigenvalue according to Perron-Frobenius Theorem

Since such vector is normalized the sum of all of its components is equal to one.

Firstly, the pair-wise matrix is normalized by summing the elements in each column and dividing them with the corresponding calculated sum. In this way the sum of all the elements of the same column of the matrix would be 1.

Secondly, the criteria weight vector is developed by averaging the elements on each row of the normalized pair- wise matrix.

Consistency check

To verify the coherence in the values attributed to the pair-wise matrix a consistency check ought to be done. A matrix and subsequently the weights assigned are consistent if they are transitive. This condition indicates that the order of the different elements is respected. The matrix with the defined attributes can either be *absolutely consistent* when decision- makers give perfect judgements or *not absolutely consistent* (Alonso and Lamata, 2006).

In his work (Saaty, 2008) states that *absolute consistency* is achieved if:

- $a_{ij} \times a_{jk} = a_{ik} \left(\forall i,j,k\right)$
- λ_{max}=n
- CI=0

For decision-making purposes taking into consideration human judgements such conditions are unrealistic. In the cases of not absolute consistency if the matrix is not contradictory the highest eigenvalue is greater than *n* (λ_{max}>n). In such cases Saaty proposes the measurement of the level of inconsistency using the consistency ratio CR, calculated as follows:

$$CR = \frac{CI}{RI} \qquad (5.6)$$

where, CI is the Consistency Index and RI is the Random Index.

The CI is defined by Saaty as:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5.7}$$

where, λ_{max} is the highest eigen value, and *n* is the order of the pairwise matrix.

RI, represents an average value of CI generated using the Saaty scale. Various authors have computed RI values based on the order of the matrix using simulations methods. In their work (Alonso and Lamata, 2006) summarized some of the RI values based on several sources and a characteristic table with RI values that will be used in this research is as follows:

Table 5.7 Average Random Indexes for n-order matrix

n	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

According to (Saaty, 2008) a matrix is accepted as consistent or nearly consistent if the value of the Consistency Ratio (CR) is no greater than 0.1 ($CR<0.1$). Since absolute consistency is achieved when $\lambda_{max}=n$, a value of CR very near to zero reflects low level of inconsistency.

5.5.3 Aggregation

The procedure of standardization and weighting at each level of the defined hierarchy is followed by the aggregation process. In the aggregation process the entire information is combined to give a final decision model, which in the context of decision- making is known as *the alternative* while for the purpose of the dissertation it represents the *risk level*.

One of the most used aggregation methods is the weighted linear combination (Malczewski, 2000), in which each standardized (normalized) parameter is multiplied by the relative weight and the results being summed to give the final goal. The following equation might be used to evaluate alternatives (Malczewski, 2000):

$$V(x_i) = \sum_j w_j v_j (x_i) \tag{5.8}$$

where $\mathbf{w_j}$ is a normalized weight such that ∑wj=1(see 5.5.2), $\mathbf{v_j(x_i)}$ is the value function for the **j-th** parameter (attribute) while $\mathbf{V(x_i)}$ represents the value of the alternative or main objective based on the value of the **j-th** attribute. The equation is applied for all levels of the hierarchy as shown in the simplified scheme below. For instance, the value of attributes or parameters at the lowest level of the hierarchy is defined using value functions, then the elements in the second level are calculated using Eq. 5.8. The input for application of the equation are the values and weights of the attributes located below this level. The process is repeated until the final objective is calculated.

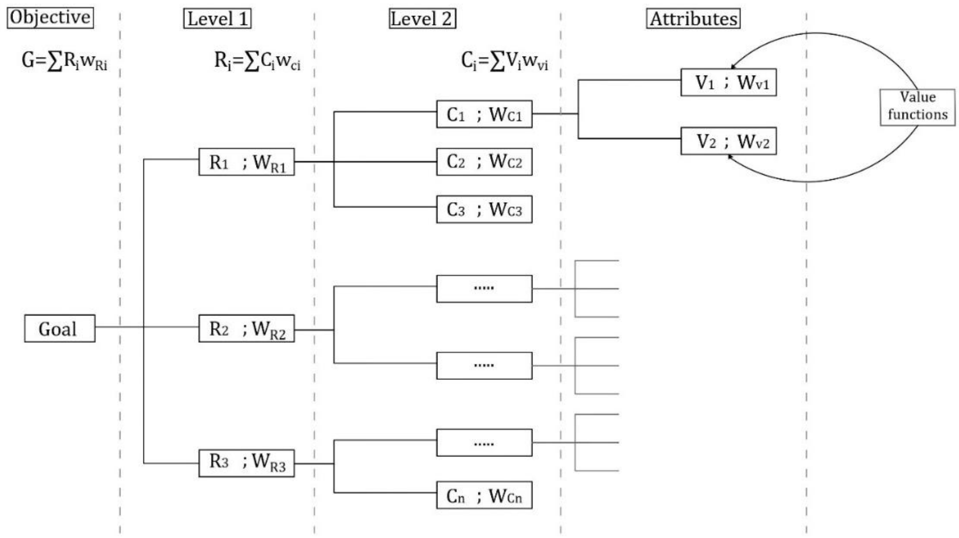


Figure 5.13 Simplified scheme of the aggregation process

Part 2

Methodological Approach

6 The Methodology

Based on the theoretical aspects discussed extensively in the previous chapters related initially to the multidisciplinary context of the problem, the methodology is developed taking into consideration the principles of a Spatial Multi- Criteria Evaluation method (5.5). The proposed methodological approach has a focus on the multi-criterial, multi-disciplinarity and multi-scale aspects of seismic risk.

Following the aim of the research thus, the development of a methodology that can be used for decision- making purposes with an inclusive participation of different stakeholders during prescreening processes, this chapter focuses in detail on structuring the problem in such a way to be transparent and easily integrated as a tool or complementary information for planning.

For the proposed methodology the urban scale is carefully connected with the operational or building scale, in order to fully support and reflect the relationship amongst these scales and the importance they have in developing proper adaptive measures to mitigate the effects of seismic events.

A clear definition of the hierarchy structure is given in terms of hierarchic levels used and relevant qualitative and quantitative indicators that characterize hazard, vulnerability and exposure. This process is then followed by the standardization of each indicator (parameter) using appropriate value functions and for each level of the hierarchy pairwise comparison matrices are developed to give the relative importance of each element. The validation of the methodology is done through its implementation in different case studies, as it will be shown in the final chapter of the research.

6.1 Structure definition

The evaluation of the risk, regardless of the approach requires a well-defined structure in which the constituting elements and selected indicators are organized and displayed in a hierarchical way. A clear and understandable structure is essential for decision-making since the organization of the corresponding information and indicators is given in such a way as to present as clearly as possible the impact of each of these indicators in the final required output.

For the purpose of this research, based on the context and the definition of risk the selected hierarchical structure is organized in four levels as shown below:

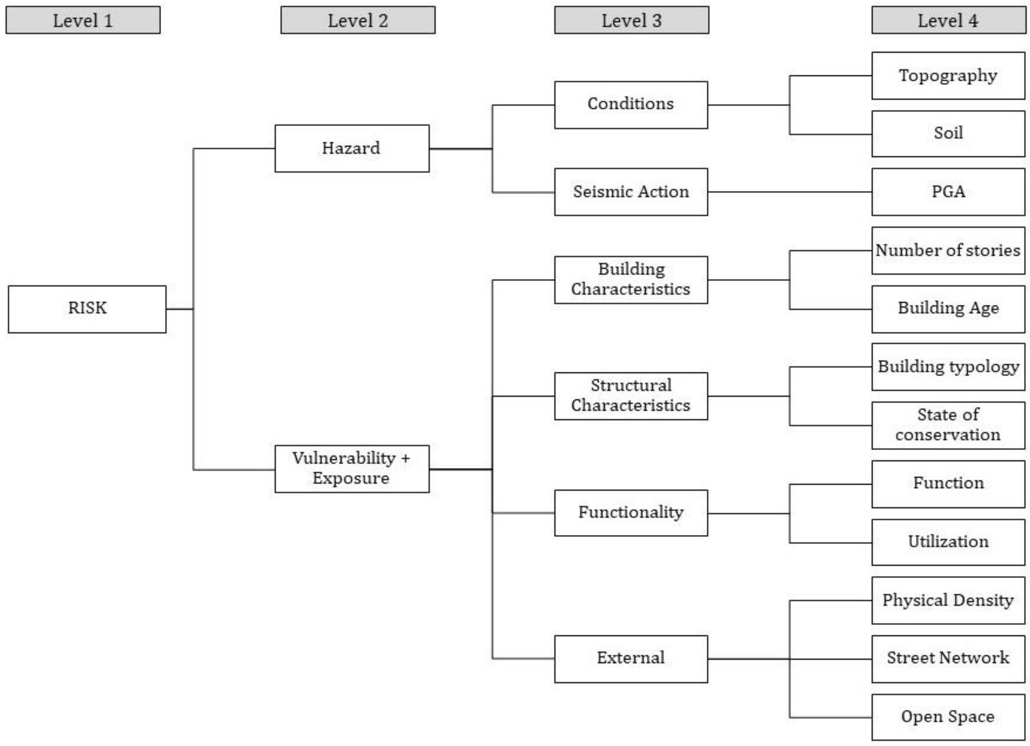


Figure 6.1 Hierarchical Structure

The first level from a decision-maker point of view represents the alternative to be evaluated and it corresponds to the level of risk, specifically seismic risk. Based on the defined concept of risk, its three constituting elements (hazard, vulnerability and exposure) are part of the second level. For a clear and specific analysis of each of the risk elements a third level is added. The final level (4th level) has all the defined variables. The variables will be standardized and weighted to assess the risk. An exemption is done for the external elements, in which an additional 5th level will be used explained in the following paragraphs.

Relevant literature and several sources define a high number of variables that can be used to evaluate the seismic risk based on the purpose of the study, the selected approach, data availability etc. Given the objectives of this research, one of the most important factors that should be taken into account in determining the indicators is the scale of the problem.

Literature provides a considerable number of studies dealing with seismic risk, from qualitative to advanced quantitative methodologies, each one of which having its own indicators. Many indicators, are undoubtedly common no matter the approach, but others differ. One of the reasons for such change is *the scale* of the problem at hand.

From a structural point of view, assessing the risk means focusing on the building scale and predicting possible consequences to the specific building. Such assessment, requires a high amount of data in this scale, for instance (Kassem, Mohamed Nazri and Noroozinejad Farsangi, 2020) in their work investigate the indices and methodologies in seismic risk to quantify the level of damages to structural elements or to the entire structural system. Parameters like the organization of structural system, configuration of plan layout, configuration in heights, elements of low ductility, non-structural elements etc. are analyzed and quantified to evaluate seismic risk.

Instead, from an urban planning point of view the focus is in integrating such building scale into a larger urban scale to help decision makers in defining prevention strategies. Therefore, the indicators have a more inclusive nature with the aim of connecting these two scales. In addition, for planning purposes beside physical indicators other non-physical indicators are quantified to evaluate economic or social vulnerability like population density, social disparity, development level etc.

In the proposed hierarchy such interrelationship between scales is given by combining into the vulnerability and exposure indicators that are related to building scale (building characteristic, structural characteristics) with external indicators (physical density, street network and open space). In addition, indicators related to functionality (function and utilization) are also introduced to take into account the level of people exposure and critical structures.

6.1.1 Hazard Indicators

Hazard component of risk, positioned at the second level of the hierarchy is analyzed in two directions, represented by two separate components in the third level; *the conditions* and *seismic action*. The combination of these two elements would give the severity of a future possible seismic action.

Seismic action

The ground motion caused by an earthquake can be described in terms of displacement, velocity, and acceleration. The dynamic forces that earthquakes induce in soils and structures are directly related to acceleration and this is the reason why in most cases seismic action is characterized in terms of acceleration values.

Ground motion has vertical and horizontal components, but for most of the cases the values of horizontal acceleration are greater than the vertical acceleration and the maximum horizontal value of acceleration is known as peak ground acceleration (Day, 2002). The evaluation of this parameter represents a challenging task since it is an acceleration induced by a possible future earthquake. According to (Day, 2002) two of the most used methods to determine the peak ground acceleration at a site are:

- Historical earthquake- Past earthquakes can be used to determine the maximum acceleration registered using seismograph for more recent events or historical accounts of damage for older earthquakes which can be converted in magnitude
- Regulatory requirements- Local building codes and regulations may specify the design values of peak ground acceleration

Peak ground acceleration values, as shown in previous chapters, is given in form of mapped information. Since it represents an acceleration, the unit is m/s^2, and in design practices is often expressed as a function of $g = 9.81\ m/s^2$. For instance, a value of 0.3g of the pga shows that the acceleration induced by an earthquake at a specific location has a value of 30% of the vertical gravity acceleration.

For the purpose of the research the seismic action is going to be characterized by the value of reference peak ground acceleration on type A ground (rock) a_{gR} as suggested by Eurocode 8. The values are obtained by relevant national authorities.

Conditions

Ground motions vary from site to site during the same earthquake. The reason for these changes is due to a large number of factors that may affect their characteristics. Waves during their path from the source of the earthquake up to the surface pass through complex stratification thus changing their velocity and sustaining multiple reflections and refractions. Amongst many factors, some of the most important affecting ground motion are the following (Villaverde, 2009):

1. Type of the fault generating the earthquake
2. Orientation of the fault with respect to the site
3. Direction of fault rupture with respect to site
4. Dimensions of ruptured area
5. Depth of ruptured area
6. Earthquake Magnitude
7. Distance from fault to site
8. Geological characteristics of soil stratifications
9. Local soil properties and topography
10. Size and type of structure on site

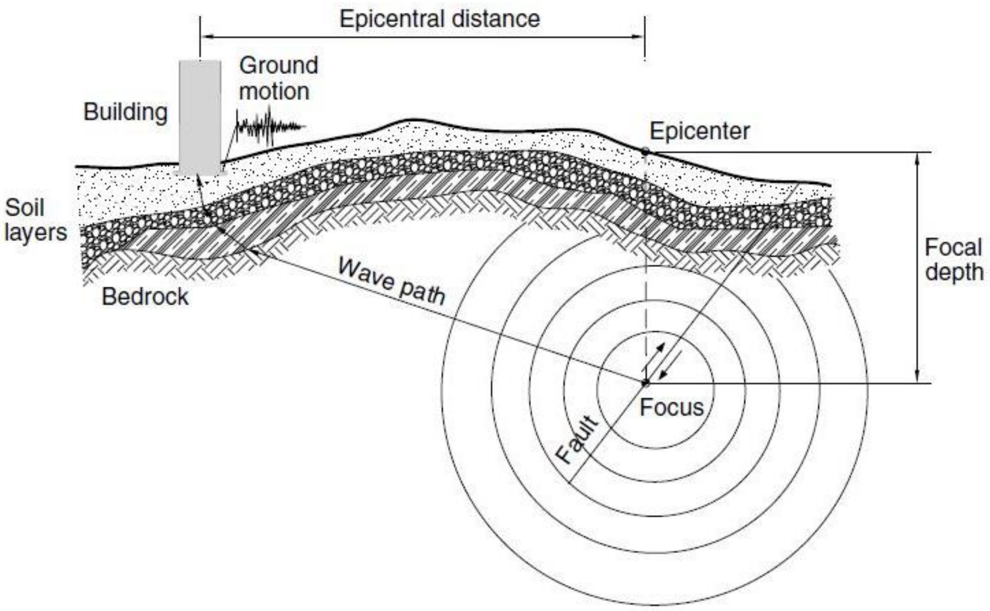


Figure 6.2Factors affecting characteristics of ground motion at a site (Villaverde, 2009)

For the purpose of the research, based on data availability and relevance of the problem only local soil properties and topography are selected as factors that would affect ground motion properties at a site. To the remaining factors, a great importance is given in the fields of studies related to geosciences. As seen in the hierarchical structure, both soil and topography represent a different branch.

Local soil conditions

In the cases when sites are located above soft soil deposits like saturated clay, there could be a high chance of amplification of the peak ground acceleration and of the other ground motion parameters. The value of such acceleration is calculated for the bedrock and then based on the conditions of soil deposits the value changes from layer to layer up to the surface where the foundations of buildings are located.

The analysis of soil conditions is complex, since different structures behave in different ways based on their stiffness and other engineering parameters. As part of structural analysis is of fundamental importance to avoid what is known as resonance, during which the frequency of vibration of the structure matches that of the ground itself. Within same site, thorough analysis of the behavior of different buildings, with different heights and structural configuration is of utmost importance. The impact of local ground conditions is well reflected for instance, during the *Michoacan Earthquake in Mexico* on September, 1985 and the *Loma Prieta Earthquake* in San Francisco Bay on October, 1989.

According to *Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for building*, ground types are classified in groups from A to E with two special ground types S_1 and S_2 (Pitilakis, Riga, & Anastasiadis, 2015) to account for the influence of local ground conditions on the seismic action. For most applications of this code, the hazard is described by the reference peak ground acceleration on rocks (which corresponds to type A ground).

Table 6.1 Ground Types (adapted from Anastasiadis & Riga, 2013)

Ground Type	Description of the stratigraphic profile			
		Vs,30 (m/s)	NSPT (blows/30cm)	Cu (kPa)
A	Rock or other rock-like geological formation, including at most 5m of weaker material at the surface	>800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth	360-800	>50	>250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters	180-360	15-50	70-250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	<180	<15	<70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5m and 20m, underlain by stiffer material with v_s>800m/s			
S_1	Deposits consisting, or containing a layer at least 10m thick, of soft clays/silts with a high plasticity index (PI>40) and high water content	<100 (indicative)	-	10-20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A- E or S_1			

Taking into consideration the ground types, the earthquake motion at a given point and the response of the systems is represented by what is known as *elastic response spectrum*, $S_e(T)$. The spectrum gives in a graphical way the response in terms of acceleration, velocity or displacement of single-degree-of-freedom systems to a certain seismic action.

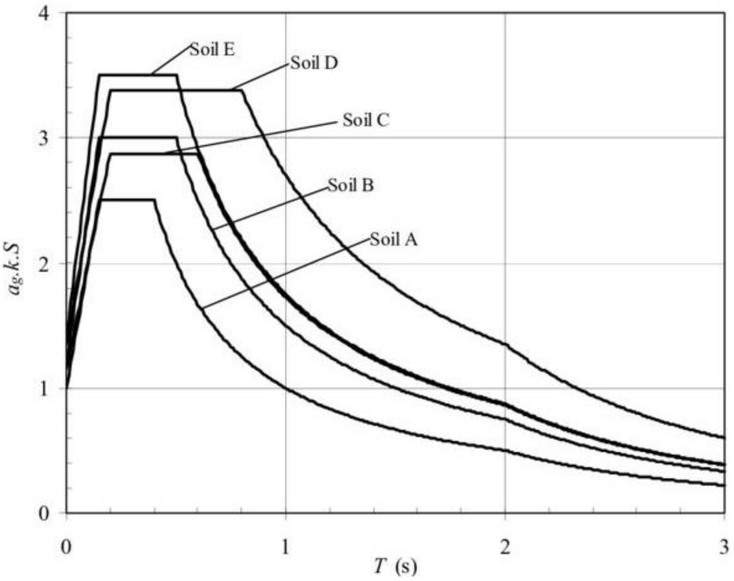


Figure 6.3 Recommended Type 1 elastic response spectra 5% damping (EN 1998-1, 2004)

Usually there are two types of response spectra used; type one is used for earthquakes with a magnitude 5.5 or greater, for lower magnitudes type two spectra is used instead. The role of local soil conditions is taken into account by inputting in the equations the soil factor S and parameters T_B, T_C and T_D. For type 1 spectra for instance the values are as given in the following table:

Table 6.2 Values of the parameters for the Type 1 elastic response spectrum (EN 1998-1, 2004)

Ground Type	S	T_B(s)	T_C(s)	T_D(s)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.2	0.6	2.0
D	1.35	0.2	0.8	2.0
E	1.4	0.15	0.5	2.0

The elastic response spectrum is then modified to take into account the capacity of structural systems to resist seismic action in the non-linear range. The modified response spectrum is known as *design spectrum*. However, based on the purpose of the research, such information will not be further detailed.

The standardization process for the soil component will be generated taking into account the aforementioned soil types and the effects they have based on the response spectrum provided by EN 1998-1.

Topographic conditions

Past historical earthquakes and detailed analyses have shown that topographic configuration has an impact on ground motion levels caused by a seismic action. The analysis of topographic irregularities is a complicated problem since the interaction of waves produce complex patterns of amplification based on the geometry of the irregularity or the frequencies of waves. However, in many cases, simplified approaches can be used in cases of ridge-valley terrain where the effect is amplified based on the vertex angle of the crest. Studies have shown that accelerations measured along the ridge change from base to the crest, achieving a value up to 2.5 times greater on the crest that on the base.

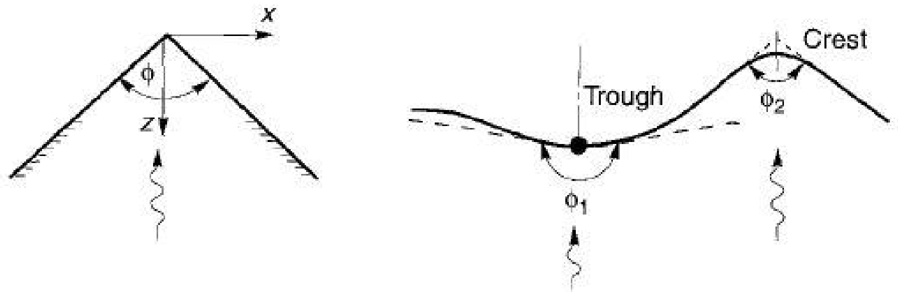


Figure 6.4 Characterization of simple topographic irregularities (Kramer, 1996)

Another important topographic feature that affects ground motion is the basin. The curvature of the basin where soft alluvial soils have been deposited affects the body waves as they propagate in this medium producing longer and stronger shakes.

EN 1998- Part 5, gives recommendations about the effects of the topography in the ground motion. The effects are taken into consideration by integrating in the design response spectrum a constant scaling factor denoted S_T, which multiplies the ordinates of such spectrum. The recommended values of the topographic amplification factor are given in the table below:

Table 6.3 Topographic amplification factors according to EN 1998- Part 5

Topographic conditions	Amplification Factor
Average slopes with angle <15°	Not considered
Isolated cliffs and slopes	$S_T \geq 1.2$ for sites near the top edge
Ridges with crest width significantly less than the base width	$S_T \geq 1.4$ near the top of slopes for angles >30° and a value of $S_T \geq 1.2$ for smaller slope angles
Presence of a loose surface layer	The smallest S_T value given in cases above should be increased by at least 20%

A triggering effect in cases of slopes during an earthquake relates to the stability of the slope. Ground motion, combined with the characteristics of slope in terms of geometry and soil could cause a failure surface. Thus, for these cases special analysis is necessary to avoid such dangerous events.

The standardization procedure for the topography will take into consideration topographic irregularities and basin effects combined with recommendations provided by Eurocode 8.

6.1.2 Vulnerability and Exposure Indicators

As mentioned in the previous chapters, the vulnerability and exposure are related to the built environment and the characteristics that make it prone to damages and losses from a possible future seismic event. In this research the focus is on physical features to characterize physical vulnerability, these features are classified into; *building characteristics*, *structural characteristics*, *functionality* and *external characteristics*.

Building characteristics

In analyzing a building stock and the response to a future seismic action, structural and non-structural characteristics are taken into account. Building characteristics, positioned in the third level of the proposed hierarchy structure aims at representing the non-structural features of an object that have an impact in the seismic performance. There is a wide literature that deals with seismic performance of different structural systems and the parameters affecting such performance. *Number of storeys* and *building age* are selected as the most representative parameters in this group.

Number of storeys

The selection of this parameter as an influencing factor in the overall risk evaluation relates to the level of exposure and to the overall seismic performance of a building. From the exposure point of view, an increase in number of storeys tends to be associated with an increase of the overall number of people living and using these buildings. On the other hand, from a seismic performance point of view, the number of storeys is related to the building height.

A study by (Ozmen, Inel & Meral, 2013) aimed at understanding the seismic behavior of low and mid-rise reinforced concrete buildings showed that among many parameters the number of storeys had an impact in the performance, where generally low- rise buildings had better seismic performance than mid-rise and high-rise buildings. Nevertheless, such information is also tightly related to the soil category where the building is located and detailed analysis might be needed.

Building age

Building age is a variable that is correlated directly or indirectly with other parameters like building typology or state of conservation. Building construction techniques and materials have changed throughout the years due to technological advancement and the possibility of using new materials. In addition, due to many external factors and loads applied during a building lifetime, the capacity to resist action from a seismic event is reduced and to improve the performance several mitigation techniques are included such as retrofitting.

The categorization of building stock based on their age, is widely accepted to be related to the national building standards and implemented codes throughout the years thus, making such categorization variable and a function of the country or region of interest. The building classification in Albania (Guri et al., 2020) is going to be used as the main reference for this category, according to which generally the buildings are classified into five main groups based on the period of construction.

Table 6.4 Building classification and typologies for Albania (adapted from Guri et al., 2021)

Period	Characteristics
Before 1944	low rise buildings, based on traditional experience
From 1944 to 1963	low-rise buildings based on KTP- 1952, unreinforced masonry
From 1964 to 1978	low to mid-rise buildings based on KTP- 1963, unreinforced masonry
From 1979 to 1990	mid-rise buildings, based on KTP-9-78 with RC beams and slabs
Post 1990	mid to high-rise buildings, based on KTP-N.2-89 and Eurocode, mostly RC frame with masonry infills

Structural characteristics

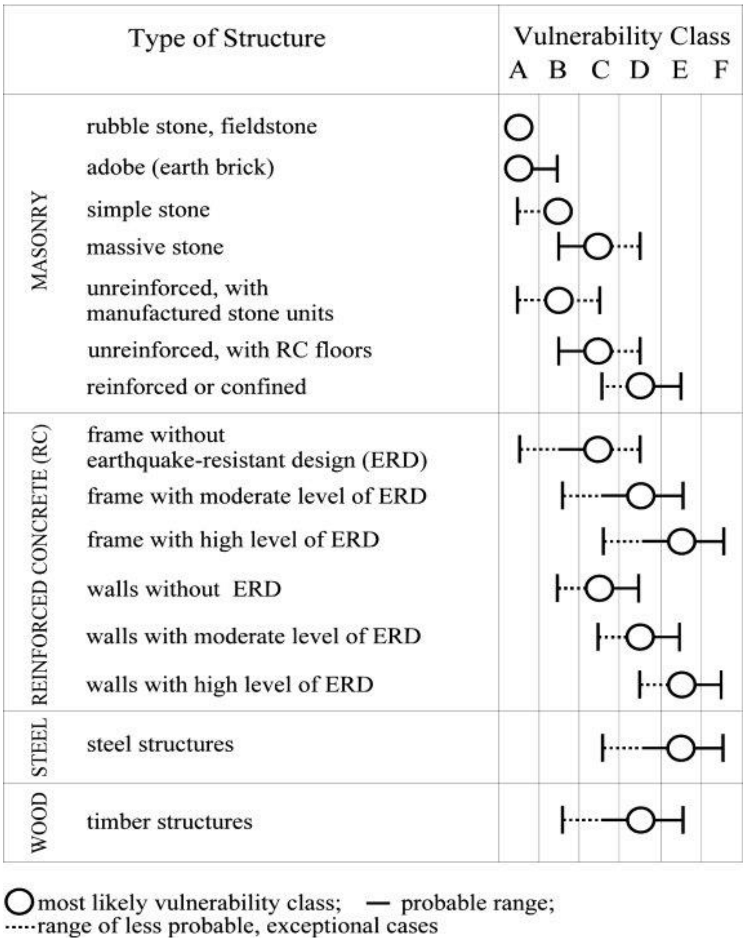
Structural characteristics are also located in the third level of the hierarchy and the analysis of it is done based on the *building typology* and *state of conservation*. The first parameter aims at analyzing buildings based on the predefined building typologies as a function of the structural system and the vulnerability of these systems. On the other hand, state of conservation analyzes the current state of the buildings, with a focus not only at the structural elements, but also of other non-structural elements that may have potential domino effects during a seismic event.

Building typology

Seismic vulnerability assessment at an urban scale represents a challenging task due to the number of structures that are present in a building stock and their variability in terms of the building typologies and construction techniques. Therefore, the analysis in this scale requires a typological classification and the extrapolation of these defined typologies in the urban building stock. (Lestuzzi et al., 2016)

In this research, the main reference for such classification is the building typology and vulnerability classes given by the EMS-98, in which to different typologies of structures; Masonry (M1-M7), Reinforced Concrete (RC1-RC6), Steel (S) and Timber (T) are attributed vulnerability classes from A to F as shown below:

Table 6.5 Vulnerability classes of building typologies according to the EMS-98 scale (Modica et al., 2020)



The structural typology of the buildings is one of the most important parameters that determine the behavior during a seismic event, since the configuration in plan and height of structural elements and the selected structural system directly impacts in the period of vibration, displacement of buildings or potential torsional effects. In this research it is decided to switch to a more simplified version of the aforementioned classification due to the scale of the problem. The building typologies used will be explained in the value function section.

State of conservation

The assessment of the current state of buildings is a delicate and complicated topic since it requires the combination of many elements within a building which when combined give the overall state of conservation. The information may be collected through site inspections, analysis of existing projects and computational simulations.

Based on the context of this research, sources availability and time the assessment of the existing state of conservation can be done in two ways:

a. *Detailed assessment,* in which the overall state of conservation of a building is assessed by the evaluation of specific elements and their state of conservation. Each element can be put in a comparison matrix and their sum would give the overall state of the buildings. Some main elements that could be analyzed are:

- External interventions- interventions that impact the structure including changes on building configuration, extra balconies, interventions for openings like windows, doors etc.
- Degradation- take into consideration the effects of atmospheric factors, presence of humidity, wind, corrosion which deteriorate the existing structure
- Previous structural damages- existing damages from previous events, external or internal cracks on structural elements
- Quality of design and materials- wrong or insufficient design criteria and analysis combined with poor quality materials highly impact on the existing state of a buildings

b. *Simplified assessment,* that can be used when there is a large number of buildings and there are time restrictions. In this simplified approach, the state of conservation is assessed through a fast exterior procedure taking into account the structural system of the building and the period of construction. There is no need for detailed analysis and the actual state of conservation can be defined based on generalized recommendations.

For the purpose of the research, the second approach is believed to be more feasible taking into account the scale of the problem in hand. Four possible alternatives are taken into consideration as follows:

Very Good - buildings with no damages, the structure is in very good condition and there is no sign of interventions or deterioration

Good - buildings with no apparent damages, the structure is in good conditions with slight signs of deterioration due to age or atmospheric agents.

Poor - buildings with slight damages, most of them nonstructural and with signs of deterioration, humidity or corrosion

Very Poor - buildings with clear damages, cracks in structural elements, partial collapses and deteriorated elements.

Functionality

The introduction of functionality through the means of **function** and **utilization** parameters is done to assess the criticality or sensitiveness of the buildings within an urban system. If an asset within a system has a significant importance and its disruption would possibly cause severe consequences it is considered as critical infrastructure (Huang, Liou & Chuang, 2014). Therefore, they are considered much more sensitive than other assets of the same system when dealing with the consequences a hazardous event might have. Critical infrastructures might include elements like; hospitals, first-aid clinics, police, fire stations, energy supply, water supply, gas supply etc. Within the functionality category, the cultural value of a building can also be integrated as a complementary criterion. For the purpose of this research, to better reflect the level of exposure the function of a building is combined to the *utilization* in terms of people using that facility.

Function

As aforementioned, there are many elements of an urban system that can be considered critical and other less critical, so a challenge would be the categorization of the variety of buildings that can be found within these systems. Some approaches choose to categorize the infrastructures within an urban system based on the period of time these infrastructures can stop operating. For the purpose of this research, objects of an urban system based on the function are categorized as follows:

- Category 1- Includes buildings that cannot stop operating and their possible disruption during a seismic event could hinder the entire system during the emergency and non- emergency phase. Buildings like hospitals, fire stations, emergency services, water and energy supply facilities are included.
- Category 2- In this category there are included buildings which have the possibility of having high level of exposure, or the buildings that during a post-earthquake situation can be used to evacuated affected population due to the area they provide. Some of the most representative objects of this category are the big commercial centers, restaurants, coffee shops, hotels and objects with a mix function.

- Category 3- This category is dedicated to buildings having a residential function including single story houses up to residential blocks. The difference between them is then given in the **use** variable
- Category 4- Buildings considered less sensitive are included in this category, whose disruption does not affect significantly the urban system and the inhabitants. Small shops, recreational and sports facilities, abandoned buildings are some representatives of this category

Utilization

The second parameter within the "Functionality" category is the utilization. Through this parameter it is attempted to integrate in the model the rate of use of each building. When talking about the use there can be defined two basic data; firstly, *the density of people* on the buildings which can be simply expressed as the average number of people located in the buildings either during the peak hours or during the entire day. Secondly, the time of daily use of the same buildings, which can be seen as the total hours the building is used at its peak capacity or the time the same building has a specific number of people considered as critical. For the purpose of this research, an attempt has been made to make a combination of both data in qualitative terms. The generalized nature of the following classification may represent a slight setback in this research which can be improved in the future through the introduction of quantitative data, which on the other hand are considered easily measurable.

By combining the aforementioned data four qualitative categories are proposed for this indicator as explained below, with the symbol "U" representing utilization:

- U1- buildings considered with a high density of people and a very high daily use frequency. Multi-story residential buildings, hotels are an example that can be included in this category since they both have a large number of inhabitants and in this work are considered with a high frequency since they are inhabited 24h a day.
- U2- low density and high daily use frequency. Part of this category are object that are used through all day, which do not have a significant number of people compared to U1. Small residential buildings of 1 to 4 storeys, hospitals and other emergency buildings are some examples.
- U3- high density and low daily use frequency. Buildings that have concentration of people during specific time of the day. Big commercial centers, restaurants, offices, recreational and sportive areas or museums are part of this category.

- U4- low density and low daily use frequency. In this category are considered buildings that are not used, due to the fact of being abandoned, out of function. Buildings having an important cultural value, but that are not open to public are also part of this category

The specific categorization of the buildings within a specific case study can be done by consulting different experts and stakeholders, through the analysis of relevant data.

External

It is highly argued that the conceptualization of risk has been fragmentary instead of integral based on the discipline involved in its evaluation. At an urban scale, the vulnerability should be related not only with the characteristics of the building stock but also its surrounding. In addition, a holistic approach requires the analysis of social components in terms of population, age, economic and social gap etc.

The integration of physical density, street network and open space as external elements aims at giving the relation between buildings and infrastructures within an urban system. The relation between the building stock and external urban elements is important in the analysis of seismic risk because it is directly related to the different stages of risk management as well as the exposure of the elements at risk.

Due to the complexity of urban systems, based on expert opinions and relevant literature it was decided that for the external elements a new level is added (5^{th} level) to better describe the influence each of the elements has on the urban seismic risk as shown in the following scheme. The combination of the two lowest levels gives a total of **14 variables** that need to be evaluated, five are used to characterize external elements, three for the hazard characterization and six for building characterization.

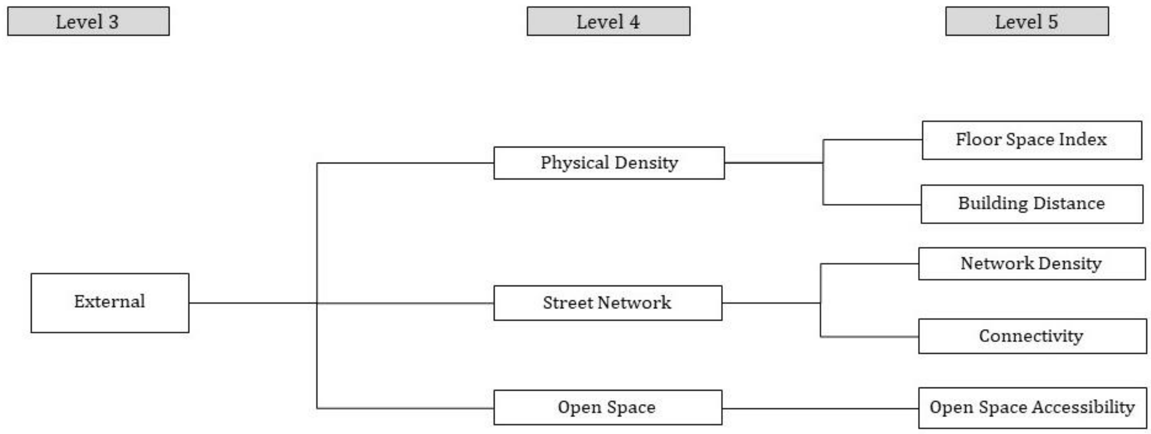


Figure 6.5 Hierarchic Structure for External component

Physical Density

Density is considered as one of the main standards to analyze a built area. Physical characteristics of built areas are measured using different indicators, which take the form of coefficients expressed as a ratio in which the denominator is the total area of the land where density is measured, while on the other hand the numerator is variable and it may represent elements like homes, people, rooms or total available floor areas (Pont & Haupt, 2005).

Two of the most common variables used to measure the physical density of a built area in a zonal level (scale 1:1000- 1:2500) are the *dwelling density* and *FAR* (Floor Area Ratio) which can be also found as FSI (Floor Space Index). Other additional variables like Ground Space Index (GSI), Open Space Ratio (OSR) and Layer (L) are used with the aim of improving the way in which built space is described. Density has an influence not only on the spatial configuration and living quality of a space, but also on the response an urban system has when facing a natural disaster, as it is the case of a seismic event. Dwelling density, is expressed as the ratio of the number of dwellings to the site area:

$$d = \frac{\text{No. of dwellings}}{\text{Site Area (hectare)}} \tag{6.1}$$

Dwelling density is considered as an elastic indicator, since it does not describe in an efficient way the spatial properties of an area; it does not take into consideration the type of building, the number of floors or the spatial layout.

An alternative indicator to the dwelling density is the **Floor Space Index (FSI)** otherwise known as Intensity which is the ratio of the building's total area to the area of the parcel. It is preferable to dwelling density since it gives the number of floors and the total usable area of a building and represents one of the most used indicators in analyzing existing and future urban plans.

$$FSI = \frac{\text{Total Building Area}}{\text{Site Area}} \tag{6.2}$$

FSI is the first indicator chosen in this research to represent the influence physical density has on the entire urban system at a given zone since it roughly gives an idea also on the level of exposure in terms of people occupying the area.

The following illustrative figure helps to better understand the concept of FSI:

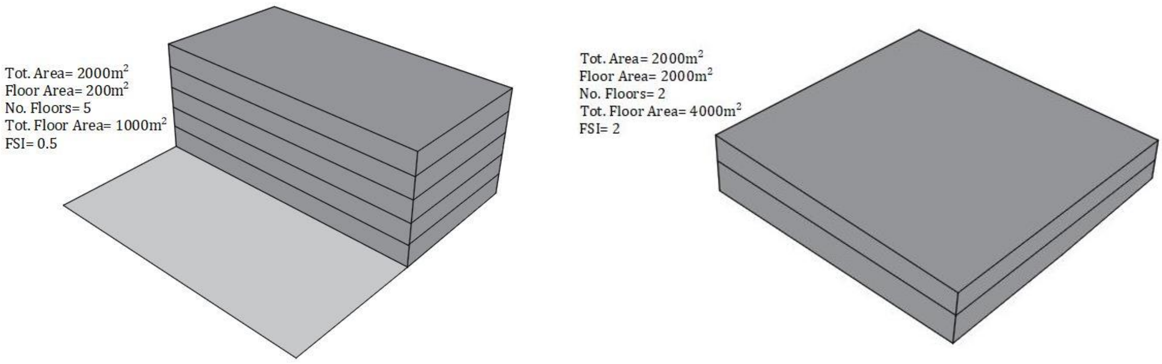


Figure 6.6 FSI calculation example

Due to the spatial configuration of the built area high levels of intensity not necessarily correspond to objects located close to each other. For this reason, **building distance** is introduced as an additional indicator to best represent the possible domino effects that may occur during a seismic event.

Building distance is measured between adjacent buildings, buildings in front of one another or between buildings and roads to ensure that the minimum requirements for fire, light and seismic standards are met.

During an earthquake, buildings pound each other if the gaps between them are insufficiently wide. This width depends on the flexibility and height of the structures, usually accepted as 2% of the building height based on the allowed seismic drift (Charleson, 2008). In the corresponding Albanian legislation and planning standards it is specified that the minimum distance between two buildings is calculated as the sum of the floors of these buildings with a 2m additional clearing space. This distance is measured from the façade of the buildings.

Street Network

One of the most fundamental elements of an urban system is the urban infrastructure which consists of elements like water supply, sewage system, electricity network and transportation or street network. Among these elements, street network has a significant role on the resilience of the urban system to the seismic event. The street network is extremely important during the emergency phase as it should provide safe evacuation of people together with quick accessibility of emergency services. The role of such network is vital also during the long-term recovery of the urban system. (Shieh, Habibi, Torabi & E. Masoumi, 2022).

In the work by (Rus, Kilar & Koren, 2020) it is emphasized that the performance of a street network is evaluated in terms of connectivity (redundancy), accessibility and centrality. Connectivity is related to the alternative options provided in case of a failure of an individual element of the network, accessibility relates to the distance of individual elements from each other while centrality indicates the importance of the network nodes in which urban functions as healthcare, schools, commerce and other important activities are usually located.

Vulnerability of the road network is a complex issue since it combines a number of factors including road width, road hierarchy, important nodes, road width-building height ratio, land use, building density etc. When analyzing the efficiency of such systems during a seismic event in most of the cases typological approaches are used based on the spatial configuration.

For the purpose of this research a simplified approach is chosen in which the role of the road network is given in terms of its coverage (network density) in a certain zone using **Street Cover Ratio (SCR)** combined with the **connectivity** of the same network, which is evaluated in terms of existing links and nodes.

SCR (Petralli et al., 2013) represents the percentage of the area covered by streets and its elements and it is the ratio of the street area to the total area of the zone. In the context of Albania this indicator is one of the most important for developing and proposing future urban plans. Another way of expressing network density (ND) is in terms of the length of the network per unit area.

Connectivity may be measured in terms of the average distance between intersections, the average node connectivity, alpha and beta indices, characteristic path length etc. Greater street connectivity implies an increase in the permeability of the urban fabric and it also reduces the distance traveled by vehicles increasing the walkability. On the other hand, increasing the connectivity in terms of nodes may result in reduction of the space to be used for other purposes as parks, open spaces or residential areas.

For the purpose of the research the measurement of the connectivity is done using the beta index (Zhang, Miller-Hooks & Denny, 2015) which is the ratio between the number of links (e) to the number of nodes (υ).

Links and nodes are elements used to represent a street network in a simplified way in the form of a graph. Based on the scale, nodes might represent road intersections, stations or even towns, while a link represents the transportation infrastructure which connects the nodes.

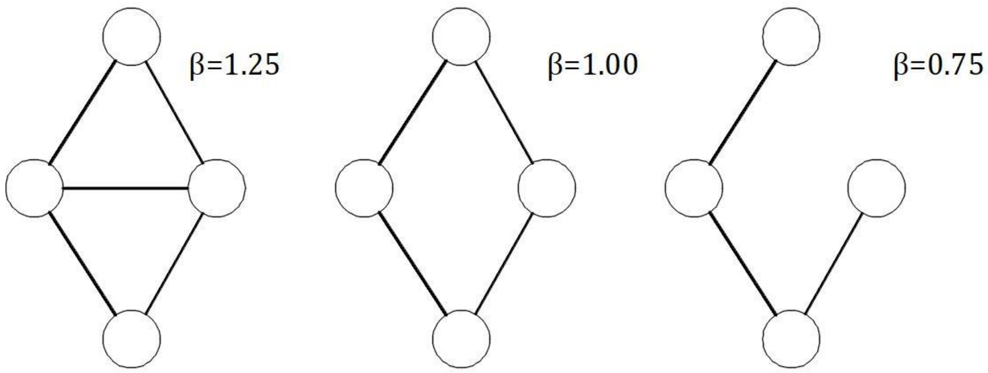


Figure 6.7 The concept of beta index in measuring connectivity

Open Space Accessibility

Within the complex urban system, open spaces are considered as key components of disaster response since they provide spare capacities for the affected population and as such, they have a direct or indirect influence on people's perception of risk (Shrestha, Sliuzas & Kuffer, 2018; Koren & Rus, 2019).

An in-depth literature study by (Koren & Rus, 2019) found that there are three main types of open spaces:

- Green open space- consisting of natural elements like soil, grass, water with little or no human intervention
- Built- up open space- consisting of built elements with little or no vegetation
- Undeveloped open space defined as residual or left-over space unfit for development but with permeability to the urban fabric.

The suitability of a specific open space is dependent on the type of disaster and the attributes of the open space itself. Some of the main attributes to characterize an open space include;

the total area of the open space, the shape, constituting elements, site conditions like the terrain, type of soil. In addition, specific spatial characteristics that connect open spaces to the entire urban system that are also relevant to the urban resilience include; accessibility, connectivity, flexibility, distribution, decentralization etc. Besides the obvious importance an open space has in case of seismic action in all phases of disaster management, unfortunately there is a lack of quantitative studies on open space in relation to seismic action and urban seismic resilience.

Among many aforementioned characteristics, a simplified approach is chosen in which the focus is on the accessibility of the open space expressed as the *distance* from a specific object to the open space. By using this indicator, it is assumed that there are no accessibility problems in terms of the open space permeability. It is noted that the impact open space has in the urban seismic resilience can be complete if other additional attributes are taken into consideration and such issue represents a potential future improvement of the proposed methodology.

6.2 Standardization of the indicators

The standardization process is conducted based on the principles explained in detail earlier in the previous chapter. For each of the selected parameters in the proposed structure the tendency, range, shape and mathematical expression will be defined. The results of the four-step analysis are represented by the corresponding value function. For the purpose of the research, it is easier to give a relationship such as higher standardized values consist in higher level of risk. In other words, *standardized values close to 1 represent the worst situation from a decision-maker point of view.*

Seismic action

The representative parameter of seismic action is the peak ground acceleration. The increase of its values results in an increase in ground motion, therefore higher values of this parameter tend to increase the level of risk.

The definition of the range is done taking into consideration the correlation between peak ground acceleration and the Modified Mercalli Intensity (MMI). Many studies give different correlations to characterize the relation between these two parameters based on the region to be applied. As a minimum threshold of the peak ground acceleration is going to be accepted the one that corresponds to an Intensity Scale of V which is explained as a moderate shaking felt by nearly everyone, with windows broken and unstable objects overturned.

On the other hand, the maximum threshold is going to be accepted the one that corresponds to an Intensity Scale of VIII, described as a severe shaking which causes slight damages in specially designed structures and considerable damage in ordinary substantial buildings with partial collapse. ("The Modified Mercalli Intensity Scale | U.S. Geological Survey", 2022). The selected maximum value of the peak ground acceleration is 0.60g, while as the minimum range the value 0 is going to be accepted in order to not neglect the effects of the ground motion corresponding to a MMI of V (approximately 0.10g).

The earthquake energy and therefore the induced damages increase exponentially with the increasing of the magnitude. Such increase is reflected in the values of the peak ground acceleration and thus, the shape of the function is selected as *convex increasing*.

The summarized information together with the corresponding value function are as follow:

Table 6.6 Peak ground acceleration value function characteristics

Parameter	**PGA**
Tendency	Increasing
Unit	g
Minimum Range	0
Maximum Range	0.60
Shape	Convex
ρ	-0.55

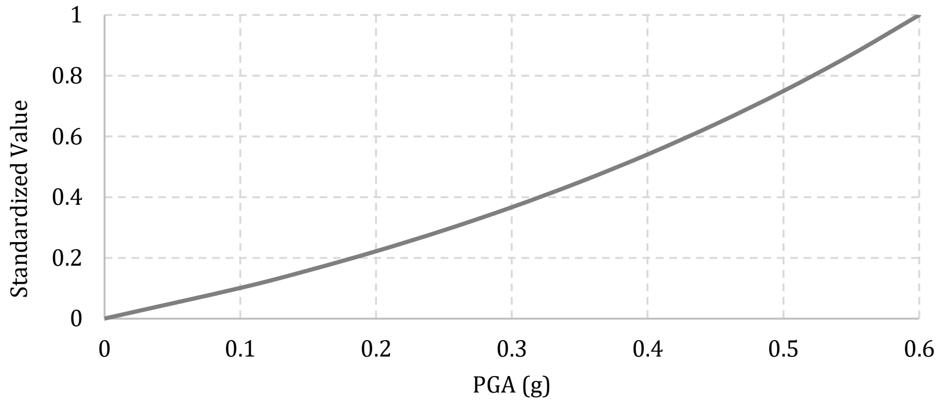


Figure 6.8 Peak ground acceleration value function

Local soil conditions

The ground types given by the Eurocode will be used as a reference for the standardization of local soil conditions. The limits of the value functions are defined by the categories from A to E, where special categories S_1 and S_2 which require special attention are not taken into account since their effect on ground motion for the purpose of this dissertation is considered to be the same as ground type E, thus representing the worst condition having a value of 1.

Ground type is considered as a qualitative parameter (variable), therefore to build a value function that gives the influence of such parameter a quantification is needed. The categories from A to E are represented by numbers from 1 to 5. Regarding the shape of the value functions, to take into account the effects of a soil deposit in comparison to firm rock a slightly *increasing concave* function is chosen with the aim of reflecting such effect.

The information for this parameter is available in the form of local maps and geotechnical reports provided by geological institutions. The selection of the ground type is done based on this available data.

Table 6.7 Ground Type value function characteristics

Parameter	Ground Type
Tendency	Increasing
Unit	-
Minimum Range	A (1)
Maximum Range	E (5)
Shape	Concave
ρ	10

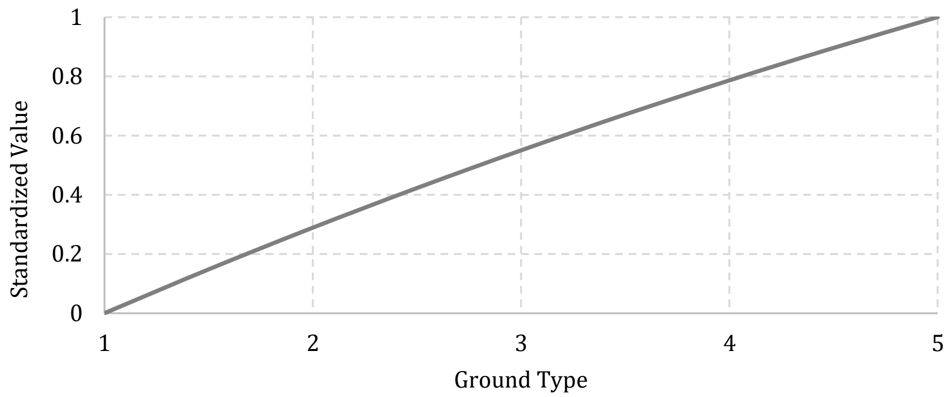


Figure 6.9 Ground Type value function

Topographic conditions

The standardization of topographic conditions that affect ground motion is going to be simplified in terms of generalized slope angles where the objects are located. The effect of the topography in ground motion is complex therefore detailed analysis are required in order to properly assess this effect.

For the topographic conditions three classes have been selected following recommendations; slopes with angles <15^o, slopes with angles 15^o-30^o and slopes with angles greater than 30^o which represent the worst situation. In the analysis is not taken into account the combination of the topography with the soil condition that might cause a slope instability and also the exact position of the object, since the amplification of ground motion is mostly felt in the crest compared to the base. The selected function for this parameter is linear with an increasing tendency.

Table 6.8 Topographic conditions value function characteristics

Parameter	Topography
Tendency	Increasing
Unit	o
Minimum Range	<15º (1)
Maximum Range	>30º (3)
Shape	Linear

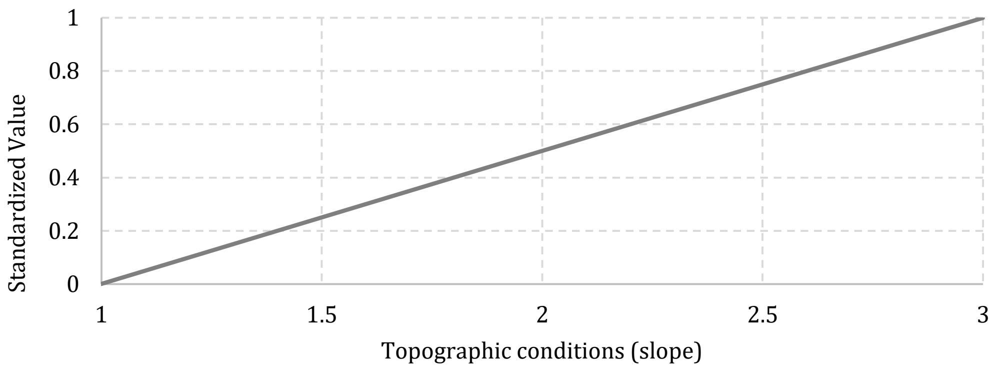


Figure 6.10 Topographic conditions (slope) value function

Number of storeys

The influence of the building height in the seismic performance is variable, for instance, low-rise buildings are more affected by high frequency waves, while high-rise buildings by low frequency waves. In addition, such influence depends on the ground type the building is located on, as specified in the previous paragraphs. Therefore, for the purpose of this research, the main factors to determine the increasing tendency of the value function for the number of storeys (building height) are the level of exposure in terms of people and the potential negative domino effects. The first aspect reflects the fact that higher buildings have more spaces and increased capacities and therefore the density of people using such spaces, no matter the function is certainly higher than for low-rise buildings. On the other hand, the toppling and domino effects of buildings, the possibility of collapsing with one another and the risk of debris fall during seismic events causing injuries is another dangerous aspect of high-rise buildings.

Based on a thorough analysis, the minimum value is assigned to buildings having number of storeys from 1-3, and the maximum to buildings having more than 15 storeys. Within this range, two additional categories are used; buildings with storeys 4-7 and 8-15. To each of the categories a number from 1 to 4 is given in order to implement such information into the equations. The selected shape for the value function is linear with an increasing tendency.

Table 6.9 Number of storeys (building height) value function characteristics

Parameter	Number of storeys
Tendency	Increasing
Unit	Storeys
Minimum Range	1-3 (1)
Maximum Range	>15 (4)
Shape	Linear

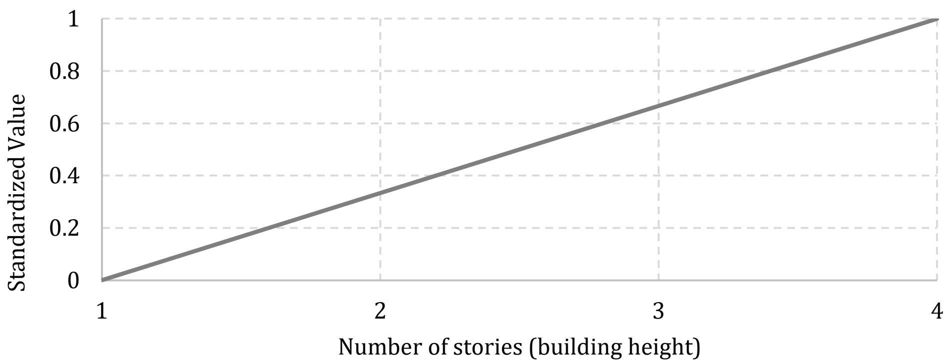


Figure 6.11 Number of storeys (building height) value function

Building age

For the building age parameter, the function has a decreasing tendency. The maximum value corresponds to older buildings as for these buildings the levels of risk are increased. As aforementioned, the generation of the value function is based on the building classification in Albania with some slight modifications. The range of this function has a minimum value corresponding to buildings constructed before 1979 and a maximum corresponding to buildings constructed after 2010. Intermediate values include buildings from 1979- 1990 and 1990- 2010.

The selected shape for the value function is *concave decreasing*, as the rate of change is considered higher for the new buildings due to the improvement in building techniques and standards.

Table 6.10 Building age value function characteristics

Parameter	Building Age
Tendency	Decreasing
Unit	Year
Minimum Range	<1979 (1)
Maximum Range	>2010 (4)
Shape	Concave
ρ	2.3

Figure 6.12 Building age value function

Building typology

As aforementioned, the structural system of a buildings is one of the main factors influencing vulnerability levels. For the standardization of such parameters a modified version of EMS 98 will be used consisting in 6 typologies. For the masonry structures the categories M1 and M2 are used to represent unreinforced masonry and reinforced or confined masonry, respectively. For the reinforced concrete categories RC1 (No Earthquake Resistant Design) and RC2 (Earthquake Resistant Design), since for the scale of the problem the differences between frame and shear wall systems in terms of vulnerability are considered negligible. Finally, two categories S and T are also used to represent Steel and Timber structures.

By ranking the structures from the most vulnerable to the least vulnerable, the tendency of the function is decreasing. Based on the EMS-98 table category M1 is considered the most vulnerable, followed by RC1, M2 and T2 are considered moderate vulnerable and S with RC2 the least vulnerable. Such ranking is based on the probable range of vulnerability classes of each category, for instance RC2 and S have the same vulnerability levels, but taking into consideration than RC2 is widely used for residential and commercial buildings and the fact that the less probable range for S gives more vulnerable levels, RC2 is considered the least vulnerable.

The building typology standardization represents a challenge due to the variability each structure has in response to a seismic event, therefore beside an application in prescreening and initial planning processes, information on such behavior must be given in a building scale in form of detailed fragility curves.

Table 6.11 Building typology value function characteristics

Parameter	**Building Typology**
Tendency	Decreasing
Unit	-
Minimum Range	M1 (1)
Maximum Range	RC2 (6)
Shape	Linear

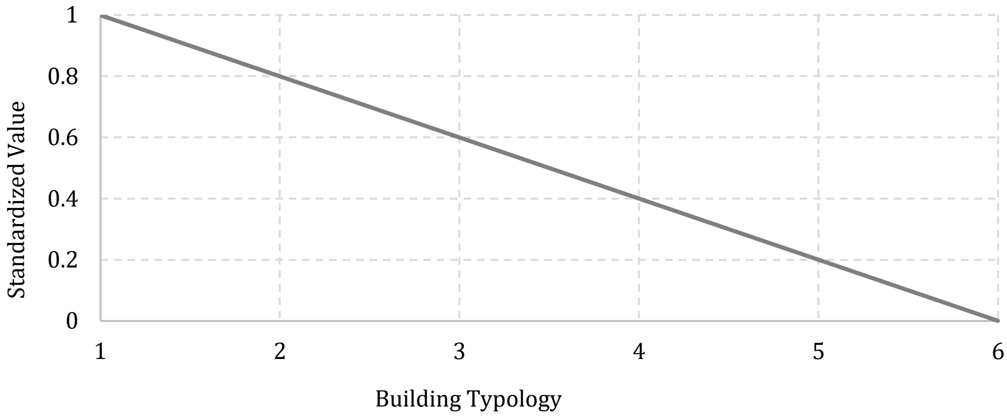


Figure 6.13 Building typology function

State of conservation

For the state of conservation, the tendency is increasing corresponding to an increase of the risk with the decrease of state of conservation. For this case the shape is decided to be an S-shape according to MIVES equation in difference by what was used for other variables. Such shape reflects small changes in the level of risk for good states of conservation and immediate increase for the two remaining alternatives (Poor and Very Poor).

Table 6.12 State of conservation value function characteristics

Parameter	State of Conservation
Tendency	Increasing
Unit	-
Minimum Range	Very Good (1)
Maximum Range	Very Poor (4)
Shape	S-shape
C	1.6
P	2.3
K	0.8

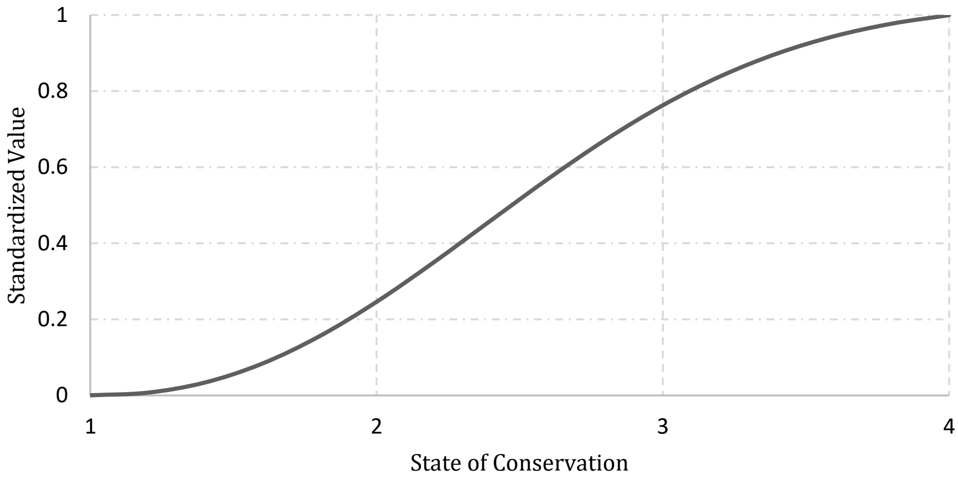


Figure 6.14 State of conservation value function

Function

The value function of this parameter is generated based on the four categories defined in the previous paragraphs. The tendency of the value is *decreasing* since going from Category 1 to Category 4 there is a decrease on the criticality of the objects. The form is selected concave with the purpose of reflecting smaller rate of change within Category 1 and 2 in terms of their criticality and higher rate of change for the following categories.

Table 6.13 "Function" value function characteristics

Parameter	**Function**
Tendency	Decreasing
Unit	-
Minimum Range	Category 1
Maximum Range	Category 4
Shape	Concave
ρ	1.5

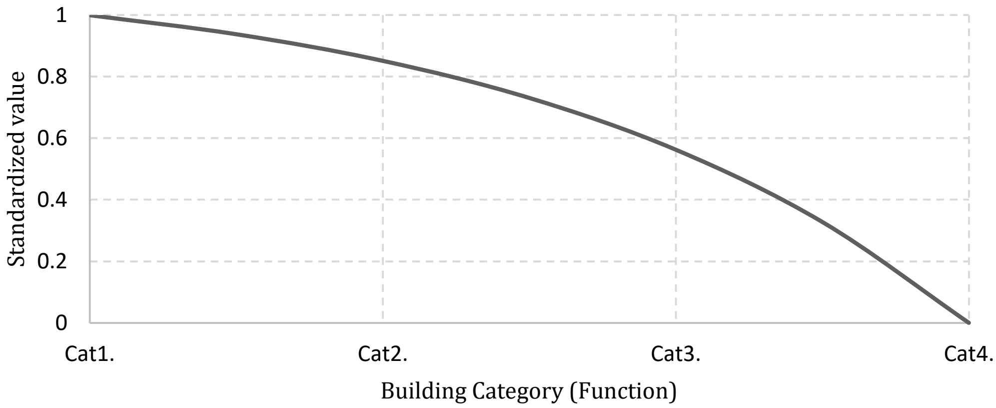


Figure 6.15 "Function" value function

Utilization

This variable is standardized taking into account the proposed categories from U1 to U4 in analogy with the *function* variable. The tendency of the function is decreasing and the shape is *concave.* Since earthquakes are unpredictable events that happen within a short period of time if the buildings are not inhabited through all the day the risk is considered to decrease exponentially, this is the reason why buildings having high frequency are considered to have higher levels of risk and there is an immediately decrease from U3 to U4 as shown in the value function below:

Table 6.14 Utilization value function characteristics

Parameter	Utilization
Tendency	Decreasing
Unit	-
Minimum Range	U1
Maximum Range	U4
Shape	Concave
ρ	0.8

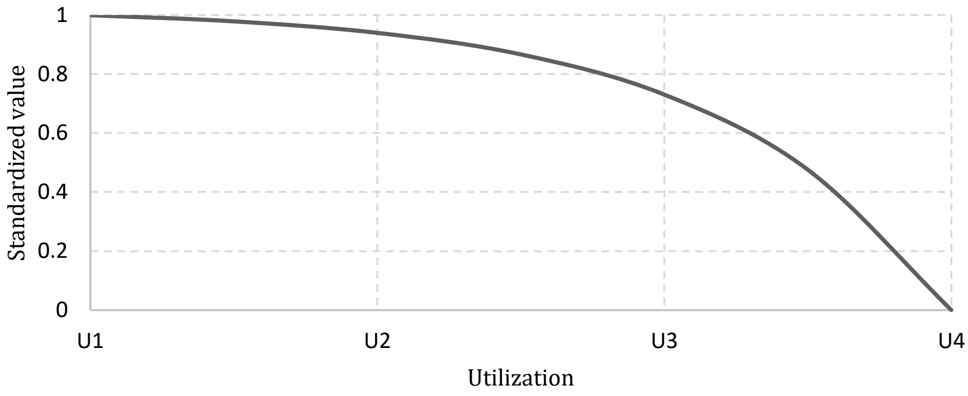


Figure 6.16 Utilization value function

Floor Space Index

The Floor Space Index is the first indicator of the physical density element that is analyzed to give the influence in the levels of seismic risk. For the development of the value function the tendency is *increasing*. Based on literature review, recommendations and planning practices in Albania the categorization of density is done based on the following ranges of the FSI; 0-1 low density, 1.1-2.5 medium density, greater than 2.5 corresponds to high density. As noted by (Churchman, 1999) the density of a certain built area is analyzed in relative terms, but without specifying absolute numbers, meaning that low, medium or high densities have different numerical values.

Therefore, the selection of the ranges is done on an interpretation taking into consideration the context of the problem and are prone to future changes based on the development or restrictions of the area where such methodology is applied.

Table 6.15 Floor Space Index value function characteristics

Parameter	FSI
Tendency	Increasing
Unit	-
Minimum Range	0-1 (1)
Maximum Range	>2.5 (3)
Shape	Convex
ρ	-0.98

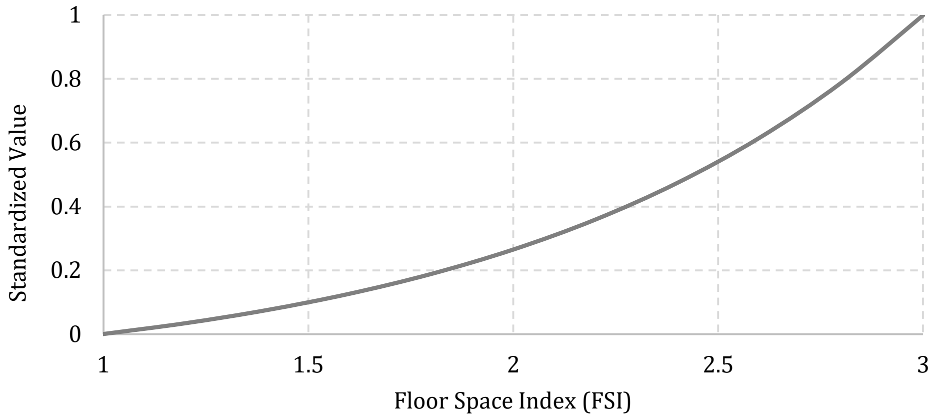


Figure 6.17 Floor Space Index value function

Building Distance

This indicator is evaluated based on the *clear space* between buildings using buffer areas by taking into consideration their height expressed in number of floors as explained in the previous paragraphs. Following recommendations, the selected range is from 0m up to 2m of clear distance. The tendency of the value function is going to be linear *decreasing* with a *convex* form since the influence of small changes near 0m is very important to avoid the pounding effect.

Table 6.16 Building Distance value function characteristics

Parameter	**Clear Space**
Tendency	Decreasing
Unit	m
Minimum Range	0
Maximum Range	2
Shape	Convex
ρ	-0.9

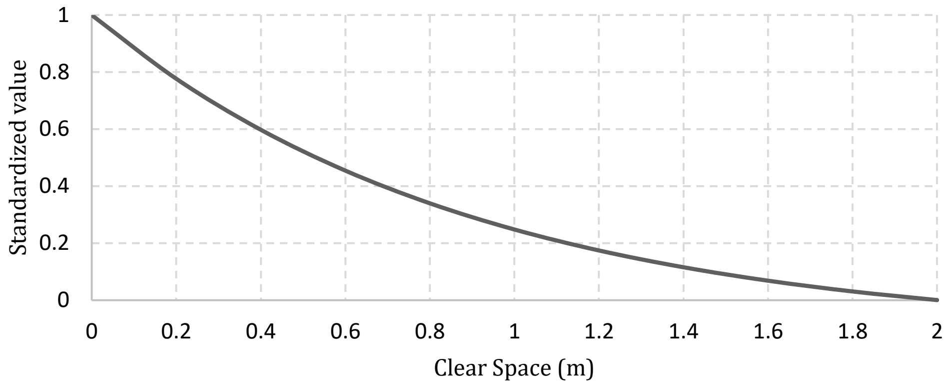


Figure 6.18 Building distance value function

Street Cover Ratio (SCR)- Network Density

Street Cover Ratio is chosen to represent the network density within an urban system. Higher density levels correspond to a more developed street network. Such indicator combined with other indexes provide an essential information when determining the levels of risk within an urban system.

The value function has a *decreasing tendency* with the worst score given to the areas having a SCR lower than 15% and the best score (1) given to the areas with a SCR greater than 22%. Two additional ranges are introduced as possible alternatives to develop the value function; 15-20% and 20-22%.

Table 6.17 Street Cover Ratio value function characteristics

Parameter	SCR
Tendency	Decreasing
Unit	%
Minimum Range	<15% (1)
Maximum Range	>22% (4)
Shape	Convex
ρ	-0.8

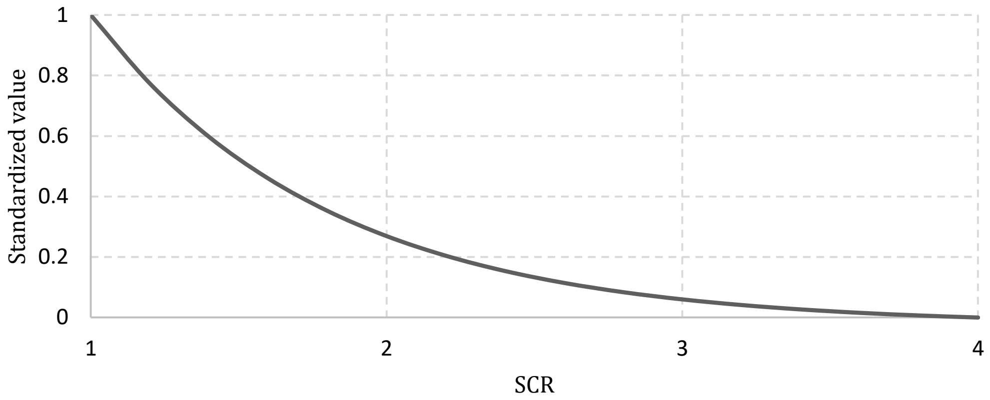


Figure 6.19 Street Cover Ratio characteristics

Beta Index (Connectivity)

Based on the graph theory for transportation network, the selected range for the beta index includes values from 0.5 up to 1.5. Since a value of 0.5 means that there are half as many links compared to the nodes it is considered as the minimum range. On the other hand, a value of 1.5 is judged to satisfy the connectivity levels corresponding to the maximum score.

The tendency of the value function is *decreasing* and the shape is selected *convex* to emphasize the positive impact beta has after a value of 1 which corresponds to networks with one cycle.

Table 6.18 Beta Index value function characteristics

Parameter	β (Connectivity)
Tendency	Decreasing
Unit	-
Minimum Range	0.5
Maximum Range	1.5
Shape	Convex
ρ	-0.95

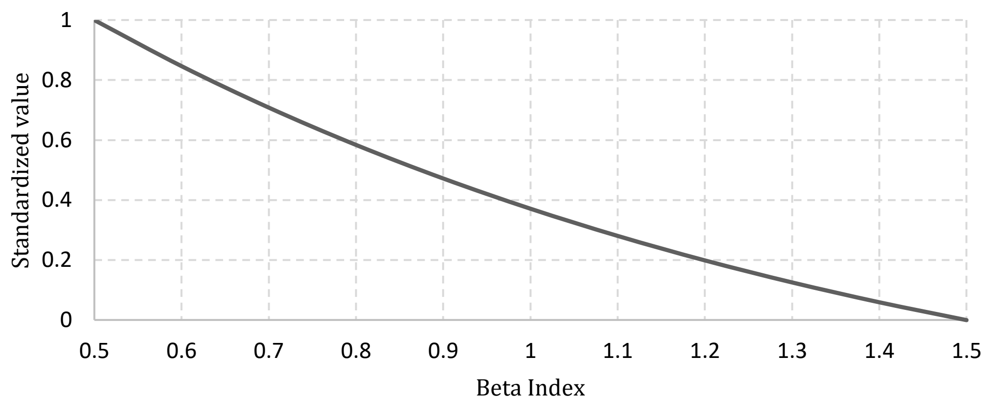


Figure 6.20 Beta Index value function

Open Space

The role of the open space in the value of risk is going to be evaluated in terms of the distance it has in relation to the objects in the specified area. For this research, any type of open space based on the classification given above is valid as long as it has the characteristics of being considered as an open space. The distance is analyzed using buffer zones starting from the specified open space. The standardization score will correspond to the position of the building in relation to the specified buffer areas. The chosen parameter tends to reflect the advantages of having closer open space areas during a seismic event in emergency phase since evacuation is much faster no matter the possible disruptions in the street network.

The extreme values are considered distances not greater than 100m having a minimum score thus corresponding to the best situation and larger than 1000m having a maximum value thus corresponding to the worst situation. The total alternatives for the distance to the open space with the corresponding values in the value function are as follows:

Table 6.19 Open Space distance alternatives

Buffer area	Value function x-axis
< 200m	1
200m - 400m	2
500m - 700m	3
800m - 1000m	4
> 1000m	5

The tendency of the function is increasing and the shape is convex as shown below:

Table 6.20 Open Space value function characteristics

Parameter	Open Space Distance
Tendency	Increasing
Unit	M
Minimum Range	<200m (1)
Maximum Range	>1000(5)
Shape	Convex
ρ	-0.95

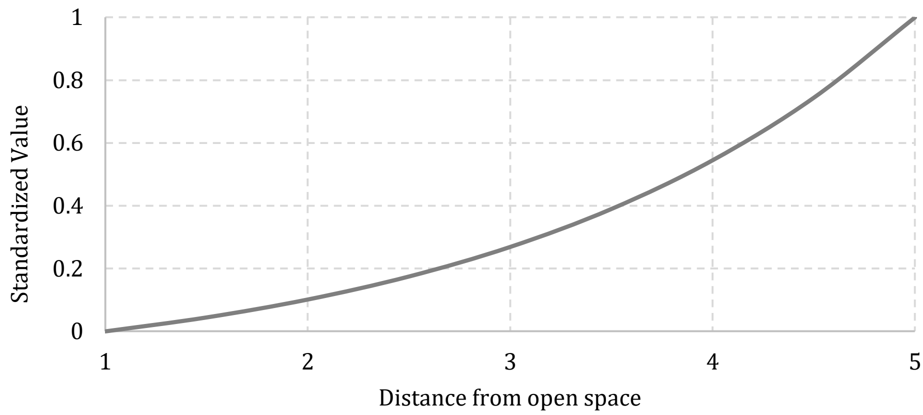


Figure 6.21 Open Space value function

6.3 Assignment of weights

The weights are assigned starting from the lower level of the hierarchy by comparing elements at the same level. The determination of the relative importance of each variable is done taking into consideration previous studies and extensive literature review combined with expert opinions using a simplified survey which includes a total of 13 questions. Each of the questions is elaborated in such a way to reflect the scale of relative importance as given in table 5.6. The detailed survey can be found on Appendix A of this research. The results for each variable of each level are explained as follows:

Conditions

To define conditions two parameters are selected; soil and topography. In their study (Tripe, Kontoe & Wong, 2013) based on extensive investigations concluded that the soil effect has a greater influence on ground motion compared to topographic effect. Such conclusion was supported by the expert asked; therefore, soil is considered strongly more important than topography based on the scale proposed by Saaty. The pair-wise comparison matrix was developed and since there are two elements the consistency of such matrix will be 0.

Table 6.21 Pairwise comparison matrix of the "conditions" elements

	Soil	Topography
Soil	1.00	5.00
Topography	0.20	1.00
Total	1.20	6.00

Table 6.22 Assigned weights and CI for the "conditions" elements

	Soil	Topography	Total	Weights
Soil	0.83	0.83	1.67	0.83
Topography	0.17	0.17	0.33	0.17
Total	1.00	1.00		
			CI	**0**

Seismic Action

For seismic action there is only one parameter taken into consideration; the peak ground acceleration, therefore there is no need to build a pairwise comparison matrix since there is no other element to compare the relative importance with. In this case the weight of the parameter is 1.

Building Characteristics

In the definition of weights for the elements constituting building characteristics branch, *building age* was selected as moderately more important than *building height* represented by the *number of storeys*. This selection is done following the suggestions of (Khan, Qureshi, Rana & Maqsoom, 2019) who emphasize that the building height compared to other parameters does not have a great influence in building performance, especially when the building is not located in soil types E.

Table 6.23 Pairwise comparison matrix of the "Building Characteristics" elements

	Building Age	Nr. Storeys
Building Age	1.00	3.00
Nr. Storeys	0.33	1.00
Total	1.33	4.00

Table 6.24 Assigned weights and CI for the "Building Characteristics" elements

	Building Age	Nr. Storeys	Total	Weights
Building Age	0.75	0.75	1.50	0.75
Nr. Storeys	0.25	0.25	0.50	0.25
Total	1.00	1.00		
			CI	**0**

Structural Characteristics

For the structural characteristics category, building typology is considered more important than state of conservation. The reason for such selection relates to the fact that buildings having a more sophisticated structural typology like the reinforced concrete would still resist better than masonry buildings in the where the state of conservation is the same. Nevertheless, state of conservation is very important as it can significantly reduce the capacity of structure to withstand loads imposed by an earthquake.

Thus, using the Saaty table and the results of the survey building typology is considered strongly more important than state of conservation as shown below:

Table 6.25 Pairwise comparison matrix of the "Structural Characteristics" elements

	Building Typology	State of Conservation
Building Typology	1.00	5.00
State of Conservation	0.20	1.00
Total	1.20	6.00

Table 6.26 Assigned weights and CI for the "Structural Characteristics" elements

	Building Typology	State of Conservation	Total	Weights
Building Typology	0.83	0.83	1.67	0.83
State of Conservation	0.17	0.17	0.33	0.17
Total	1.00	1.00		
			CI	**0**

Functionality

Within this category, function is considered with a relative importance greater than utilization. The main reason for this selection is related to the fact that no matter the utilization levels if a building considered critical is affected by a seismic event, the following impact on the entire urban system during emergency phase and recovery phase is going to be important. Nevertheless, the utilization variable is introduced to express the levels of exposure, therefore such variable cannot be neglected and for this reason following Saaty scale function is considered slightly more important than utilization.

Table 6.27 Pairwise comparison matrix of the "Functionality" elements

	Function	Utilization
Function	1.00	2.00
Utilization	0.50	1.00
Total	1.50	3.00

Table 6.28 Assigned weights and CI for the "Functionality" elements

	Function	Utilization	Total	Weights
Function	0.67	0.67	1.33	0.67
Utilization	0.33	0.33	0.67	0.33
Total	1.00	1.00		
			CI	**0**

Physical Density

For the physical density, the Intensity of the built area expressed as FSI and the building distance are taken into consideration. A higher FSI results in higher level of exposure no matter the distance between the buildings while lower FSI, but with areas in which buildings are close to one another results in higher level of vulnerability due to domino effects. Since higher levels of FSI would eventually result in buildings with reduced clear spaces, FSI is considered strongly more important.

Table 6.29 Pairwise comparison matrix of the "Physical Density" elements

	FSI	Building Distance
FSI	1.00	5.00
Building Distance	0.20	1.00
Total	1.20	6.00

Table 6.30 Assigned weights and CI for the "Physical Density" elements

	FSI	Building Distance	Total	Weights
FSI	0.50	0.50	1.00	0.5
Building Distance	0.50	0.50	1.00	0.5
Total	1.00	1.00		
			CI	**0**

Street Network

One of the most important aspects of the street network during a seismic event, is the redundancy as explained below. Following possible closures due to the debris from buildings or other damages, it is important to have alternatives for people evacuation and emergency interventions. The redundancy levels represented by the connectivity are also important for long term processes during recovery. Network density, is also an important factor, but does not reflect the efficiency of the network during an extreme event since many roads may be too narrow or not connected to nodes.

Therefore, it is selected that the connectivity (beta index) is moderately more important than the density network based on the Saaty scale.

Table 6.31 Pairwise comparison matrix of the "Street Network" elements

	SCR	β
SCR	1.00	0.33
β	3.00	1.00
Total	4.00	1.33

Table 6.32 Assigned weights and CI for the "Street Network" elements

	SCR	β	Total	Weights
SCR	0.25	0.25	0.50	0.25
β	0.75	0.75	1.50	0.75
Total	1.00	1.00		
			CI	**0**

<u>*Open Space*</u>

As for the case of the seismic action, for the open space there is only one parameter taken into consideration too, consequently the weight of the parameter is 1.

<u>External Elements</u>

Amongst the three variables used to define external elements, *physical density* is considered more important than the two other variables, respectively slightly more important than *street network* and moderately more important than *open space.* On the other hand, *street network* is considered moderately more important than *open space* based the scale of relative importance proposed by (Saaty, 2008).

Table 6.33 Pairwise comparison matrix of the "External" elements

	Physical Density	Street Network	Open Space
Physical Density	1.00	2.00	3.00
Street Network	0.50	1.00	3.00
Open Space	0.33	0.33	1.00
Total	1.83	3.33	7.00

Table 6.34 Assigned weights, CI and CR for the "External" elements

	Physical Density	Street Network	Open Space	Total	Weights
Physical Density	0.55	0.60	0.43	1.57	0.52
Street Network	0.27	0.30	0.43	1.00	0.34
Open Space	0.18	0.10	0.14	0.42	0.14
Total	1.00	1.00	1.00		
				CI	**0.0269**
				CR	**0.0464**

The generated matrix is consistent since the value of CR is smaller than 0.1 as defined by Saaty.

Hazard Component

For the hazard component of risk elements representing conditions and seismic action are taken into consideration. Since there is a tight relationship between these two elements, as explained earlier in this research, their importance is the same as shown in the following tables:

Table 6.35 Pairwise comparison matrix of the "Hazard" component

	Conditions	Seismic Action
Conditions	1.00	1.00
Seismic Action	1.00	1.00
Total	2.00	2.00

Table 6.36 Assigned weights and CI for the elements of the "Hazard" component

	Conditions	Seismic Action	Total	Weights
Conditions	0.50	0.50	1.00	0.50
Seismic Action	0.50	0.50	1.00	0.50
Total	1.00	1.00		
			CI	**0**

Vulnerability and Exposure component

For the vulnerability and exposure element it is considered that the most important parameter is the one representing structural characteristics since the level of damage is tightly related to this parameter. This parameter is followed by the functionality, since based on the function and exposure prioritization should be given to certain objects. External elements are considered more important than building characteristics as they represent key elements mostly related to the emergency phase and to the exposure.

Table 6.37 Pairwise comparison matrix of the "Vulnerability and Exposure" component

	Structural Characteristics	Functionality	External	Building Characteristics
Structural Characteristics	1.00	1.00	3.00	5.00
Functionality	1.00	1.00	3.00	4.00
External	0.33	0.25	1.00	4.00
Building Characteristics	0.20	0.25	0.25	1.00
Total	2.53	2.50	7.25	14.00

Table 6.38 Weights, CI and CR for the elements of the "Vulnerability and Exposure"

	Structural Characteristics	Functionality	External	Building Characteristics	Total	Weights
Structural Characteristics	0.39	0.40	0.41	0.36	1.57	0.39
Functionality	0.39	0.40	0.41	0.29	1.49	0.37
External	0.13	0.10	0.14	0.29	0.66	0.17
Building Characteristics	0.08	0.10	0.03	0.07	0.28	0.07
Total	1.00	1.00	1.00	1.00		
					CI	**0.028**
					CR	**0.031**

The generated matrix is consistent since the value of CR is smaller than 0.1 as defined by Saaty.

Risk

As explained several times, risk represents the final goal of the hierarchy system and it is composed by the hazard and the elements of vulnerability and exposure combined. Based on expert opinions and literature review, an acceptable approach would be that of assigning both components the same relative weight.

Table 6.39 Pairwise comparison matrix of Risk

	Hazard	V+E
Hazard	1.00	1.00
V+E	1.00	1.00
Total	2.00	2.00

Table 6.40 Assigned weights and CI for the elements of Risk

	Hazard	V+E	Total	Weights
Hazard	0.50	0.50	1.00	0.50
V+E	0.50	0.50	1.00	0.50
Total	1.00	1.00		
			CI	**1**

6.4 Vulnerability and Risk Categorization

The interpretation of the risk results obtained in the form of indices according to the aforementioned analysis can be carried out by going through a process of categorization. This process corresponds to the division and grouping of the obtained information and results in different predetermined categories. Each category has its own ranges (in terms of standardized values) and based on the position where the actual result falls into, the corresponding category is selected.

The determined categories (which on the other hand can also serve as scales in a matrix approach) need to be described properly. The qualitative or quantitative description is important, firstly to understand the actual situation and secondly to serve as starting point for proposals and recommendations in order to communicate, manage and mitigate the risk.

Many recommendations suggest that a good approach to categorize consequences and severity is by using a scale from three to five points (ISO 31010). It is believed that the larger the number of points used, the better is the judgment regarding the actual situation in terms of vulnerability levels and risk.

Based on literature review and expert opinions it was decided that for the vulnerability and exposure component five points are to be used, while for the risk four classes. The details, which are provided in the tables below give representative examples of the possible situations that might cause the prescribed levels of vulnerability. Nevertheless, it is important to note that, the described situations are not necessarily the only ones, as certain levels of vulnerability can also be caused by a combination of other external or internal factors.

Vulnerability and exposure levels are chosen to have an equal range with index interval of 0.2, while for the risk component it was decided that the highest levels of risk had a slightly larger range in comparison to low or moderate level to reflect a conservative approach.

Table 6.41 Vulnerability and Exposure classes

V+E level	Range	Description
VE1	$VE \leq 0.2$	-VERY LOW - Relatively new earthquake resistant buildings -Very low exposure levels due to low physical density, low utilization or a combination of both
VE2	$0.2 < VE \leq 0.4$	-LOW - Relatively new earthquake resistant buildings -Low exposure levels due to low physical density, combined with medium to high utilization levels and vice versa
VE3	$0.4 < VE \leq 0.6$	-MODERATE - Earthquake designed buildings combined with a non-optimal state of conservation -Moderate level of exposure

VE4	0.6 < VE ≤ 0.8	-HIGH - Relatively old building designed with old seismic specifications located in areas with moderate to high level of exposure. Visually gives the sense of insecurity
VE5	VE > 0.8	-VERY HIGH -A combination of very poor construction design and technique with very high level of exposure mainly in terms of inhabitants.

Table 6.42 Risk Classes

Risk level	Range	Description
R1	R ≤ 0.2	LOW
R2	0.2 < R ≤ 0.4	MODERATE
R3	0.4 < R ≤ 0.7	HIGH
R4	R > 0.7	EXTREME

7 Implementation

The aim of this chapter is to implement the proposed methodology (Chapter 6) in two different contexts. The first one is the historical center of Guimarães, which represents a cultural important area, protected by UNESCO and characterized by old buildings, with old construction techniques and materials. On the other hand, the methodology is also implemented in a modern and chaotic context represented by a part of the center of Lezha, a city in Albania. The selection of these two areas is based on the principle of inclusiveness and adaptability of the methodology to a changing context, avoiding therefore a context-specific approach. The applicability and the obtained results can serve as means to validate the proposed methodology.

It is aimed that the obtained results can be used for preliminary decision-making to try and improve the situation from the seismic behavior point of view not only in terms of rigid interventions, but also in terms of policies, fund allocations, dissemination and preparedness.

7.1 Case Study 1

7.1.1 Area Description

Guimarães, is a historic city located north of Portugal in the district of Braga. It is one of the most important cities in Portugal in terms of history and cultural preservation as its historical center was formally inscribed as a UNESCO World heritage site in 2001 (Granda & Ferreira, 2018). Part of the historical center is the zone selected for the implementation of the proposed methodology which is based on the work done by (Granda & Ferreira, 2018) who divide the center into 6 zones with the aim of assessing vulnerability and fire risk. Within the selected zone (specifically zone number 3) is located Largo da Oliveira, one of the most important squares from the touristic and cultural point of view.

Figure 7.1 Aerial View of the selected area in Guimarães (retrieved from Google Earth, August 2022)

The selected zone includes 73 buildings with different functionalities; from residential, to service, touristic and mix functions. As part of the historical center the buildings have similar typologies from the structural and architectural point of view.

Figure 7.2 Schematic representation of the zone limits

7.1.2 Seismic action and local ground conditions

Taking into consideration the fact that the main aim is that of the implementation of the proposed methodology to assess seismic risk it is important to thoroughly describe seismic action and local conditions as part of the hazard component of the risk, as explained in the previous chapter.

From the tectonic point of view several fault lines cross the municipality of Guimarães, where the most important ones have a direction essentially SW/NE and NW/SE. In their work (Silva, Crowley, Varum & Pinho, 2014) derived seismic hazard map of Portugal in a national scale for a probability of exceedance of 10% in 50 years, with an equivalent return period of 475 years. The mean hazard map for the entire country is shown below, in which can be seen that most of the northern part of Portugal, where Guimarães is located is characterized by values of peak ground acceleration 0.10-0.12g, relatively low values. It is important to notice that such values are reference values of acceleration for type A of the ground according to Eurocode 8. To take into account the most unfavorable scenario, the reference value of the peak ground acceleration to be used as an input for the risk assessment according to the proposed methodology is accepted as **0.12g**.

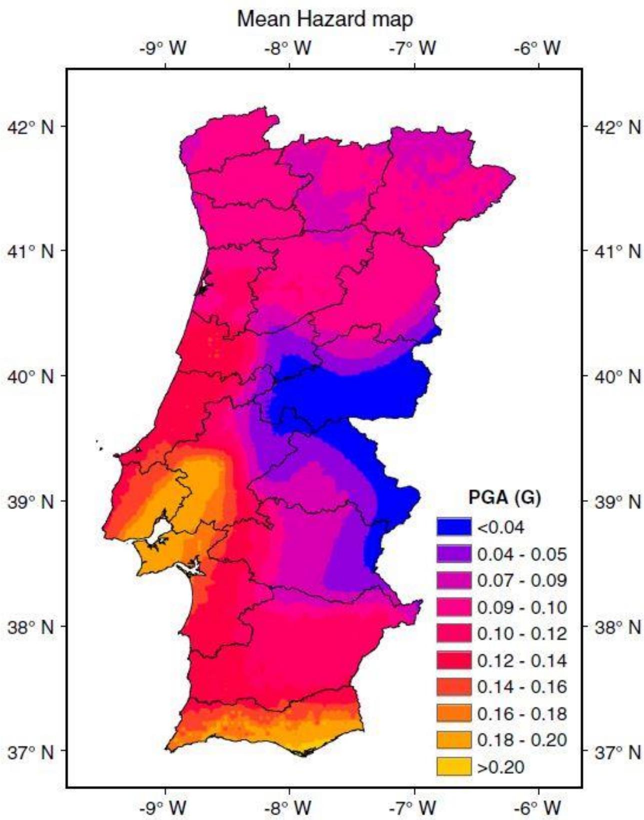


Figure 7.3 Mean Seismic hazard map of Portugal with a probability of exceedance of 10% in 50 years (Silva et al., 2014)

Based on the reports of the Municipal Master Plan of Guimarães the main geological formation of the municipality is granitic and granodioritic in nature spread across 57% of the territory. Only 4% of the county's territory is occupied by alluvium deposits near the main watercourses of Ave, Visela and Selho rivers. The nature of the bedrock and the soil deposits are important to specify the ground type according to EC-8. Due to the lack of such soil deposits and the presence of granite it is considered that for the case study the ground type category is A, reflecting good conditions from the seismic point of view.

The third variable to evaluate seismic hazard according to the methodology is the topography, the effects of this variable are analyzed at a larger scale using most of the time complex advanced mathematical models. As aforementioned, for this research a simplified approach is followed based on the EC in which the slope angle is analyzed to characterize local conditions. Therefore, within the case study area two perpendicular cross sections are taken into consideration and for each one a mean slope angle is determined. The maximum of which gives the slope angle to be used for further analysis, which for this case consists in a value of 10.8º.

The following table summarizes the results of the standardization process for the local conditions and seismic action components according to the procedure explained in detail in the previous chapter:

Table 7.1 Standardized values of the Hazard components for Guimarães

Parameter	Obtained Value	Standardized Value
PGA	0.12g	0.12
Ground Type	A	0
Topography	10.8º	0

7.1.3 Building scale analysis

For each one of the 73 units that are part of the selected area, a detailed data collection and elaboration procedure is done based on information provided from previous studies, site visits and additional data using Google Earth. Due to the scale of the problem, the procedure is characterized by a detailed analysis for each building rather than building sampling based on similar features. Part of the "building scale" analysis are the variables included in the building characteristics, structural characteristics and functionality (see Fig. 6.1).

Number of storeys

The survey data of the area showed that all the buildings had four or less storeys. Based on the categories as explained in paragraph 6.2, the majority of buildings (55%) were part of the first range with buildings having not more than three storeys, 22% of the buildings fell in the range 4-7 floors while for the remaining 23% the previous studies did not provide any information, therefore were categorized as "no details".

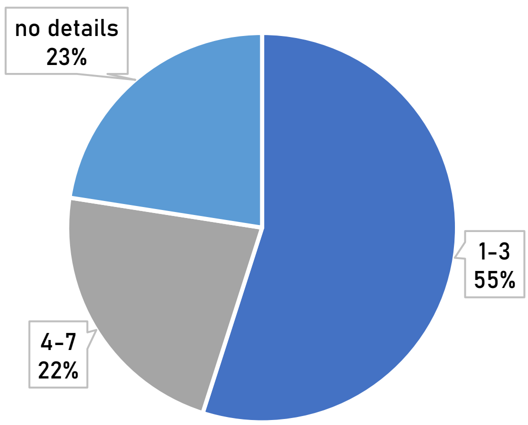


Figure 7.4 "Number of storeys" chart for the selected area in Guimarães

The following map shows the spatial distribution of the aforementioned building categories based on the number of storeys:

Figure 7.5 "Number of storeys" spatial distribution for the selected area in Guimarães

Building age and building typology

The selected area, as aforementioned is part of the historical center of the city which is part of UNESCO due to preservation of history and culture. Therefore, the buildings are characterized by the same typology in terms of structural aspects and fall within the same age range. Regarding the building typology, the technique used for the buildings of the historical center are traditional and included granite floors and walls combined with timber structures for the roof. Since the EMS 98 classification gives a specific category for stone structures, even though such buildings were not included in the standardization process, it was selected that such buildings can easily fall within the M1 category representing the worst case scenario in terms of this variable.

On the other hand, even though the city in the last century has been prone of urban changes the historical city has been intact therefore all the buildings as documented in UNESCO reports (Centre, 2022) date back to 18th- 19th century. Following the proposed categories regarding this variable, all the units of the selected area fall within the first category (<1979).

State of conservation

As aforementioned, the selected procedure for the assessment of the state of conservation is the simplified visual procedure. The reports by (Granda & Ferreira, 2018) combined with site visual inspections were important to determine the state of conservation based on the four categories. The spatial distribution of the buildings according to this variable is given in Fig 7.7 whilst the distribution in percentage is given in Fig 7.6, where most of the buildings were classified as good, due to interventions they had throughout the years, followed by buildings in a very good state.

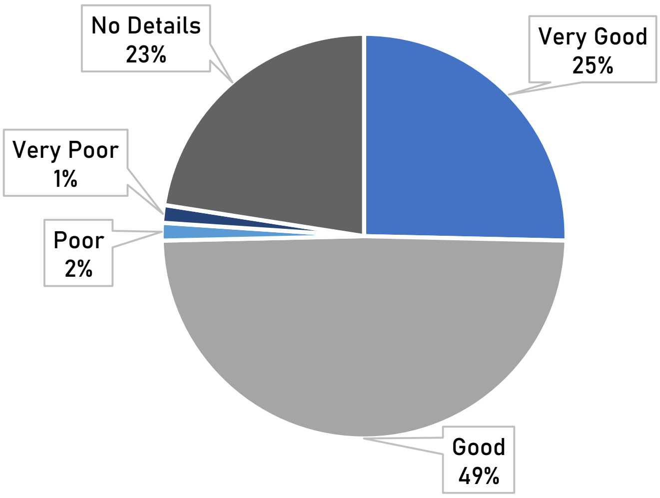


Figure 7.6 "State of conservation" chart for the selected area in Guimarães

Figure 7.7 "State of conservation" spatial distribution for the selected area in Guimarães

Function and Utilization

Starting with the function, due to the touristic importance the selected area has, as expected it was observed that the majority of the buildings have a mix function, where the first floors are usually coffee shops and restaurants and the other floors have residential purposes, followed by buildings having only residential functions. Based on the function, taking into account the occupancy time of the buildings throughout the day, the utilization for each building unit was also determined, where most of the buildings fell in U3 category, corresponding to high density and low daily use and U2 with low density and high daily use since the buildings are less than four floors and levels of exposure are considered moderate. Details for both variables are given below in the form of charts and maps to represent spatial distribution within the studied area:

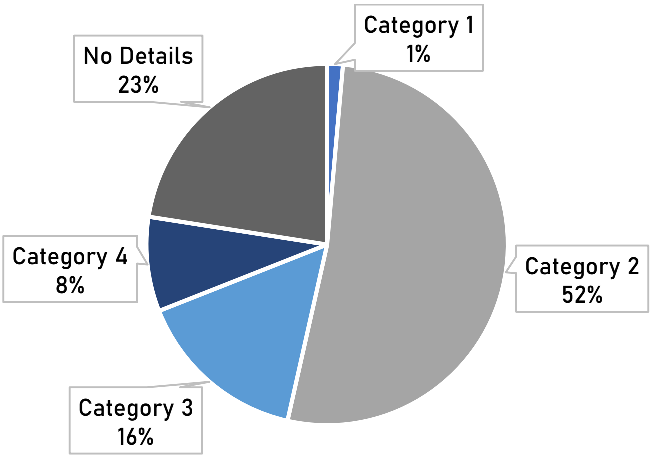


Figure 7.8 "Function" chart for the selected area in Guimarães

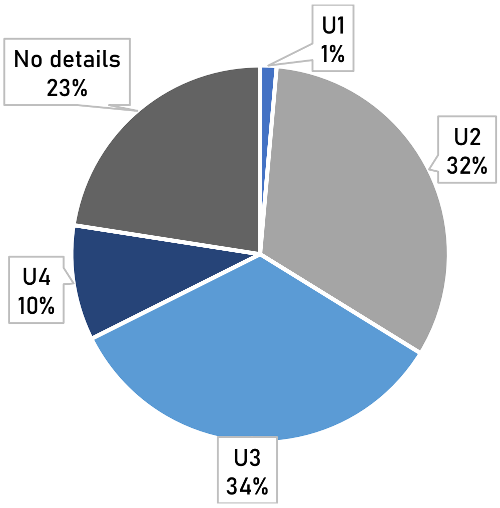


Figure 7.9 "Utilization" chart for the selected area in Guimarães

Figure 7.10 "Function" spatial distribution for the selected area in Guimarães

Figure 7.11 "Utilization" spatial distribution for the selected area in Guimarães

7.1.4 Local Scale analysis

In the local scale analysis, all the variables part of "External" level are analyzed in detail. Variables like Floor Space Index, Network Density and Connectivity are representatives for the entire area, whilst Building Distance and Open Space Accessibility are analyzed for each building. No matter this, the analysis is still considered at a local scale since it gives the relationship of each building with the built environment around, thus modelling the complex system.

Floor Space Index and Building Distance

Floor Space Index is calculated based on the building area (as a sum of the area of the total buildings) together with the site area. From the applied point of view polylines can be used to easily calculate the areas. Calculations of the area show that the total built area is 23777.95 m^2 while the area of the site is 25816m^2, thus resulting in a value of **0.92** for the FSI.

On the other hand, the entire area is characterized by adjacent buildings very close to one another with no clear distance to avoid toppling or other domino effects therefore the specific value of building distance for each unit is **0m** corresponding to the worst case.

Network Density and Connectivity

The combination of network density with the connectivity showed that the studied area in overall has a good street network. In terms of the coverage, using network density the area of streets was approximately 4225.49m^2 corresponding to a value of SCR of 16.36%, which on the other hand was standardized with a value of 0.27. On the other hand, as shown in Fig. 7.12 the connectivity levels are pleasant enhancing the permeability in the zone, nevertheless there is a slight issue at some permeable points because of the narrow streets. In total there are 8 nodes and 15 links corresponding to a value of β of 1.87. Using the corresponding value function, the standardized value of β is 0, reflecting a very good situation from this point of view.

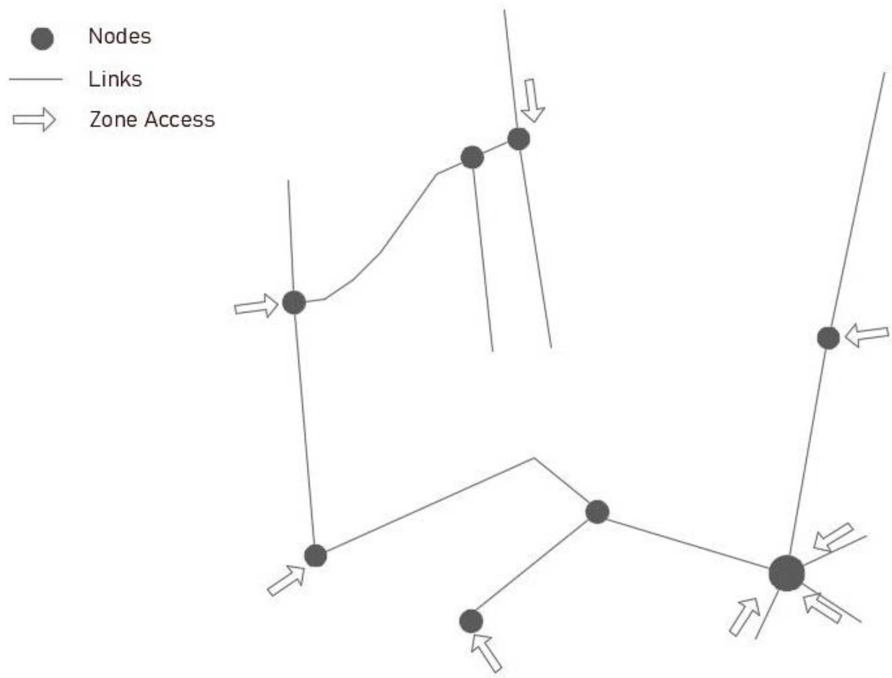


Figure 7.12 Street network diagram for the selected areas in Guimarães

Open Space Accessibility

The studied area is characterized by two main squares, two green areas and one parking lot which can easily be considered as open spaces which could accumulate people in case of extreme events. The location of these spaces is such that all buildings are located within a buffer area of less than 200m from the nearest open space, representing thus the best situation as people could be evacuated easily and fast due to the proximity to the open spaces. It is also noticed that these spaces are easily accessible due to the aforementioned street network. The distribution of open spaces is shown in the following map:

Figure 7.13 Open Space distribution for the selected area in Guimarães

7.1.5 Risk Assessment

As explained in the methodological approach, risk has been calculated combining the data in two levels; small scale and local scale, using the weighted linear combination method. As expected, due to low seismicity levels and local conditions for this case study the hazard index has an extremely low value of 0.06, reflecting thus low levels of risk even though due to building age and material the levels of vulnerability are quite high with indexed values varying in most cases from 0.6 up to 0.73. The majority of buildings, based on the results had a vulnerability level VE4, with some being part of VE3 and VE2. Another factor influencing in high levels of vulnerability is the building distance, as all the buildings are adjacent to one another. The combination of low hazard levels with a high and moderate vulnerability levels produced a risk level of R2 for almost all the buildings in the selected area which based on table 6.42 consist in moderate risk. The summarized information of the real data together with the standardized values for each of the buildings is given in the corresponding appendices (see Appendix B). The output is given in the form of vulnerability and risk maps as shown below:

Figure 7.14 Vulnerability and Exposure levels for the selected area in Guimarães

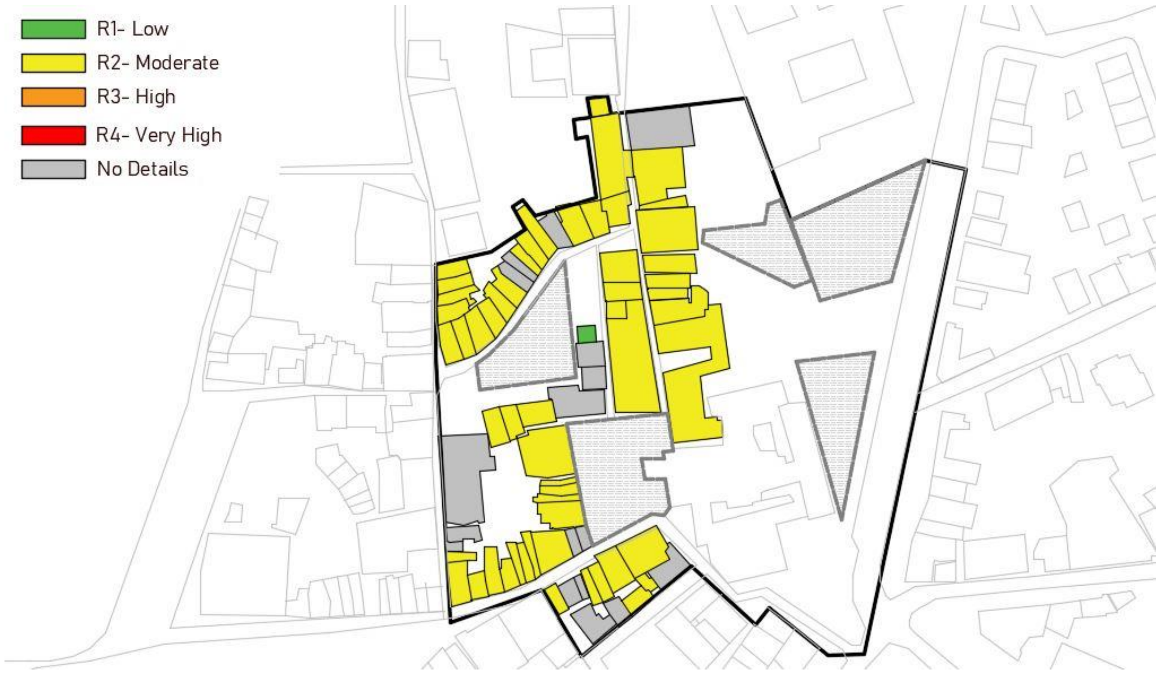


Figure 7.15 Risk levels for the selected area in Guimarães

7.2 Case Study 2

7.2.1 Area Description

The city of Lezha is located in the northwestern part of Albania, and is bordered on the western side by the Adriatic Sea. Lying on both sides of the Drin River, surrounded by the Kune - Vain lagoons as well as the Shengjin beach, Lezha represents one of the most strategic cities, offering diverse opportunities for the further development of economy and tourism. Based on actual legislation for territorial development, the municipality of Lezha as all municipalities were divided in zones, which represent existing or future areas with similar characteristics. Each unit zone is named based on the administrative unit name, territorial system and the corresponding number of the unit.

The selected zone unit for the application of the proposed methodology is LE-UB-086 with an area approximately 2.34ha as shown in the following aerial view. The building units of this area are mainly residential with high density, combined with buildings having service functions.

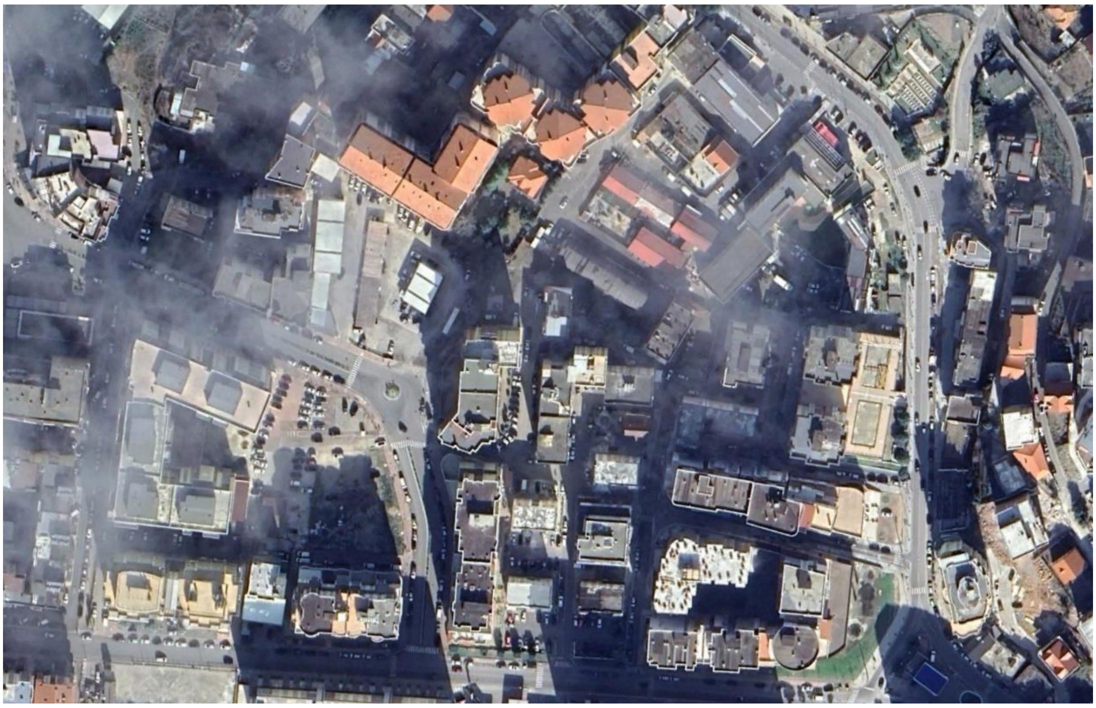


Figure 7.16 Aerial view of the LE-UB-087 unit in Lezha (retrieved from Google Earth, August 2022)

Figure 7.17 Schematic representation of zone limits

7.2.2 Seismic action and local ground conditions

The territory of the Municipality of Lezha is located along the Adriatic-Ionian seismic belt, thus having a high seismic potential. As aforementioned, the seismic hazard for Lezha is based on the study by (Aliaj et al., 2010) in which the PGA in bedrock with a probability of exceedance of 10%/50years or a return period of 475 years is evaluated. In addition, the PGA for a probability of exceedance 10%/10 years is calculated too, but taking into consideration that for anti-seismic design procedures and based on the proposed methodological approach only the former is considered relevant for this study. It is again emphasized that the values reflect the reference peak ground acceleration for rocks (type A ground), thus this value is combined with local soil conditions and topography to reflect the changes of ground motion in the surface. The following table is an adaptation of the work done for the territorial analysis of Lezha municipality, in which values of PGA for all the administrative units are given:

Table 7.2 PGA values for different administrative units (CoPlan, 2020)

Administrative Unit	10%/10 years	10%/50 years
Lezha	0.176	0.338
Shëngjin	0.176	0.338
Zejmeni	0.125	0.238
Shënkolli	0.147	0.285
Balldreni	0.176	0.338
Kallmeti	0.143	0.274
Blinishti	0.199	0.373
Dajci	0.199	0.373
Ungrej	0.114	0.208
Kolshi	0.143	0.274

The selected zone for the application of the methodology is located in the administrative unit of Lezha, therefore the selected value of **pga** that serves as an input for the implementation of the proposed methodology is **0.338g**.

The entire region the territory of Municipality of Lezha is characterized by rocks of different geological ages. Limestone, siliceous limestone, flysch, are some of the main rocks located in this area. Due to the presence of sea and Drin river, in the territory there are present alluvium deposits and deposits with fine sand which are prone to liquefaction during seismic action. The following engineering geological zoning map of the urban area is available based on several analysis and interpretation of geotechnical data obtained from field and laboratories works.

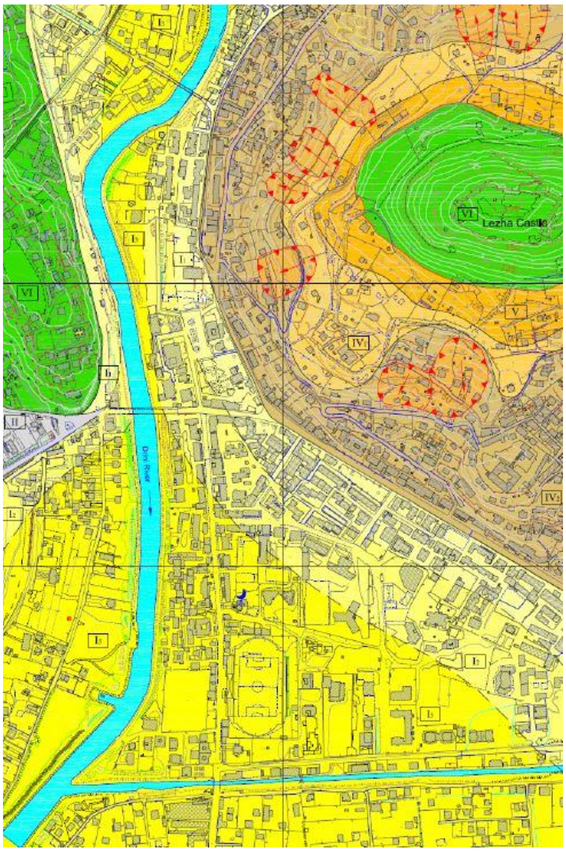


Figure 7.18 Geological zoning map of central part of Lezha urban area scale 1:10000 (Muceku, Reci, & Korini, 2013)

The mapped information provided by the National Agency for Territorial Planning (AKPT) together with the studies by the Co-Plan, Institute for Habitat Development for Lezha region give a ground type C based on Eurocodes specifications, thus corresponding to deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.

Finally, the topography as the third variable is evaluated based on the simplified approach, the same used for the first case study. The maximum angle provided by the two perpendicular cross sections at the specified area corresponds to a value of 4^{o}, which reflects good conditions. Nevertheless, in a greater scale due to the deposits and hills around the area, the basin effect might be a potential issue and a detailed study is necessary for proper evaluation.

The following table summarizes the results of the standardization process for the local conditions and seismic action components according to the procedure explained in detail in the previous chapter:

Table 7.3 Standardized values of the Hazard components for Lezhë

Parameter	Obtained Value	Standardized Value
PGA	0.338g	0.43
Ground Type	C	0.55
Topography	4º	0

7.2.3 Building scale analysis

For each one of the buildings located in the selected area, a detailed data collection and elaboration procedure is done based on information provided from previous studies, site visits and additional data using Google Earth. Due to the scale of the problem, the procedure is characterized by a detailed analysis for each building rather than building sampling based on similar features.

Number of storeys

Based on the data provided using digitalized information and fieldwork the majority of buildings (39%) were part of the second range (4-7 floors), followed by 31% of the buildings having not more than 3 stories and the remaining 17% were buildings having more than 8 storeys. Due to accessibility issues for 3 of the building units no data is provided.

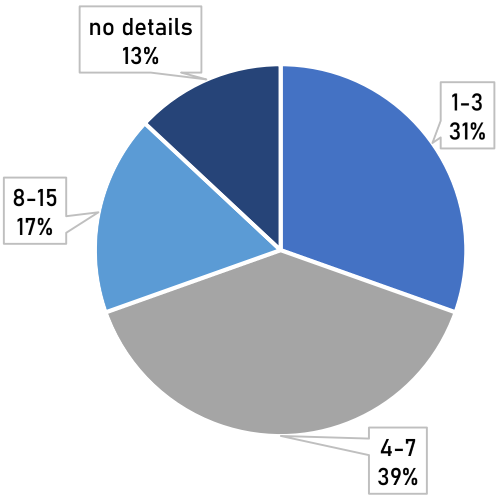


Figure 7.19"Number of storeys" chart for the selected area in Lezhë

The following map shows the spatial distribution of the aforementioned building categories based on the number of storeys:

Figure 7.20"Number of storeys" spatial distribution for the selected area in Lezhë

Building age and building typology

From the structural point of view there is a distribution of reinforced concrete buildings and masonry buildings. Due to the period of construction, most of the RC buildings are designed according to national standards rather than Eurocode specifications and for a conservative approach are defined within the RC1 category. The final distribution of buildings based on this variable is given in the chart below:

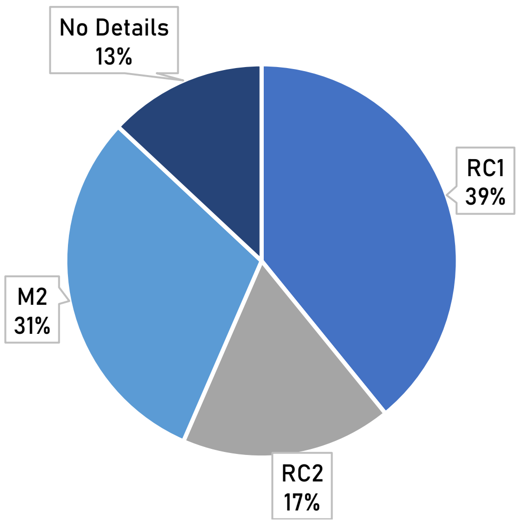


Figure 7.21"Building typology" chart for the selected area in Lezhë

The majority of buildings, approximately 48% are built during the 1990-2010 period, which corresponds to the chaotic development period, characterized by lack of legislation and restrictions from the planning and construction point of view. These buildings are followed (22%), by buildings constructed during 1979-1990 usually reinforced masonry buildings based on national building standards of that time.

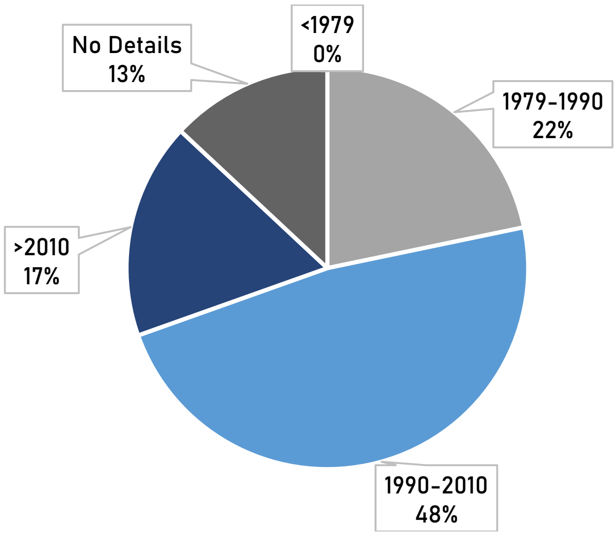


Figure 7.22 "Building age" chart for the selected area in Lezhë

The spatial distribution for the two aforementioned variables is given in the following maps:

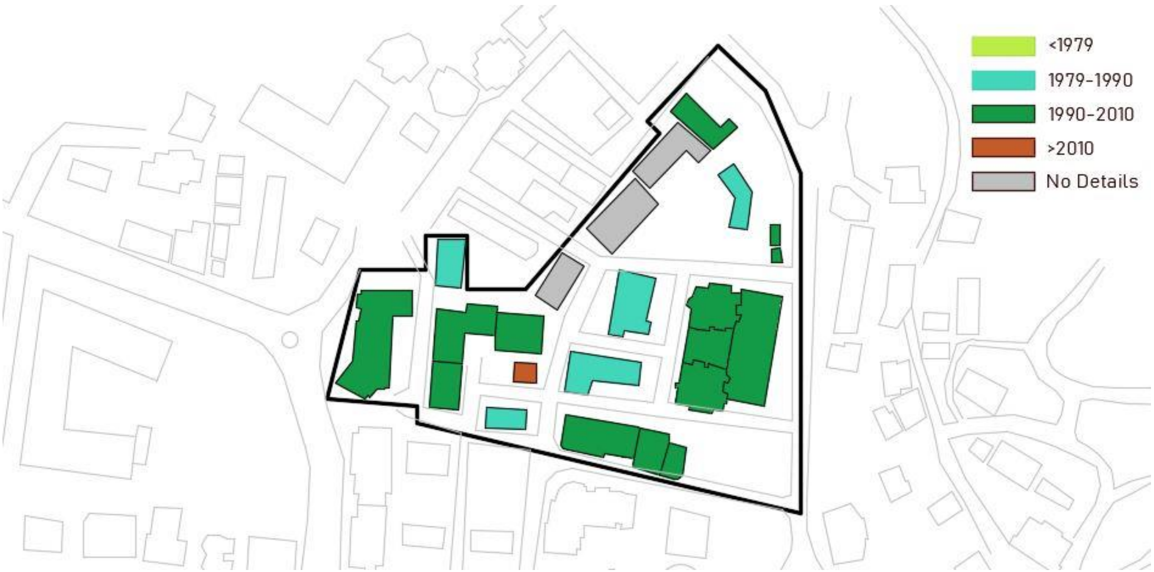


Figure 7.23 "Building age" spatial distribution for the selected area in Lezhë

Figure 7.24 "Building typology" spatial distribution for the selected area in Lezhë

State of conservation

The procedure for the assessment of the state of conservation is the same used for the first case study, thus the simplified visual procedure. The spatial distribution of the buildings according to this variable is given in Fig 7.25 whilst the distribution in percentage is given in Fig 7.26. The area is mainly characterized by buildings in a good state, representing an advantage from the seismic point of view.

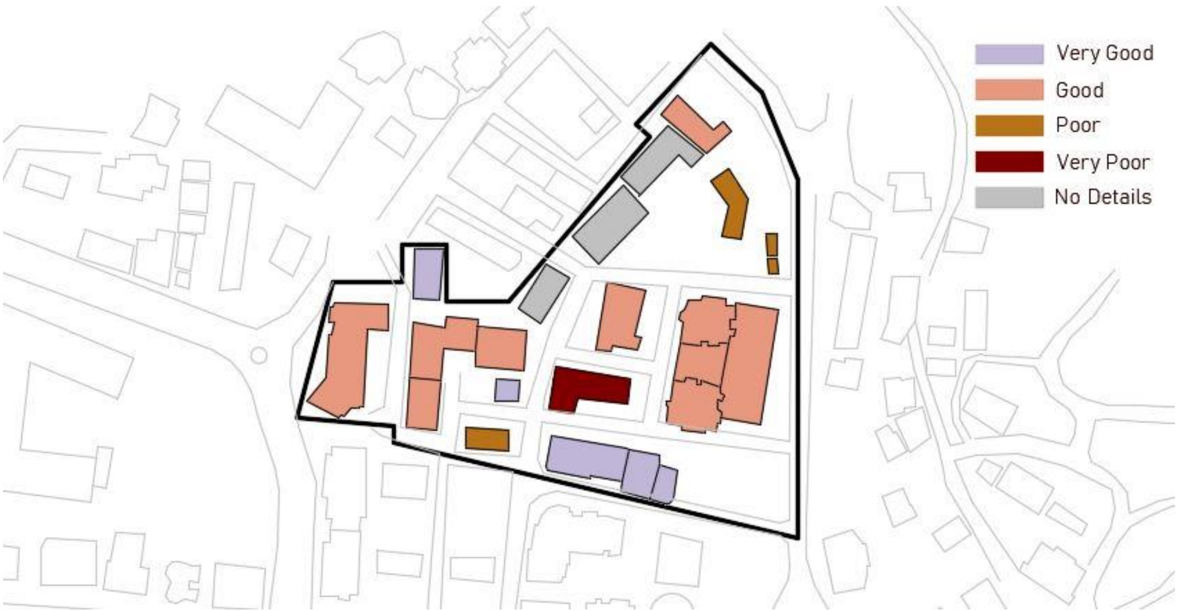


Figure 7.25 "Sate of conservation" spatial distribution for the selected area in Lezhë

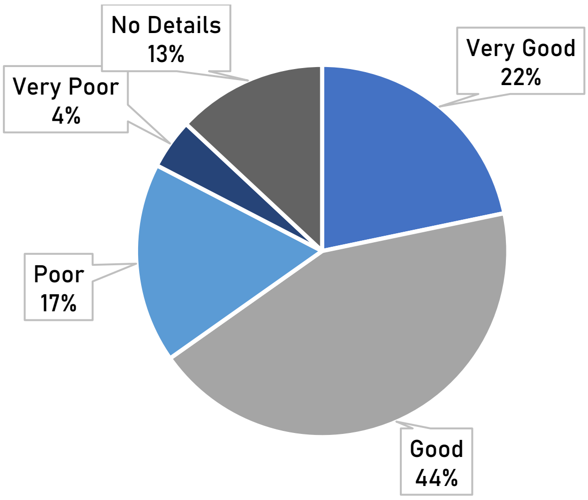


Figure 7.26 "State of conservation" chart for the selected area in Lezhë

Function and Utilization

As specified in general and local plans for Lezhë city, the function of the studied area is residential and this is also reflected in the actual state where the majority of buildings are part of Category 3, followed by buildings which have a mix or other functions (Category 2). In terms of exposure levels, due to the high-raise buildings and their residential function, most of the buildings are part of the U1 category (52%), which corresponds to dense use and long period of usage. Therefore, reflecting high level of exposure in terms of people, a disadvantage from the risk point of view. The details for these two variables are given in the following maps and charts:

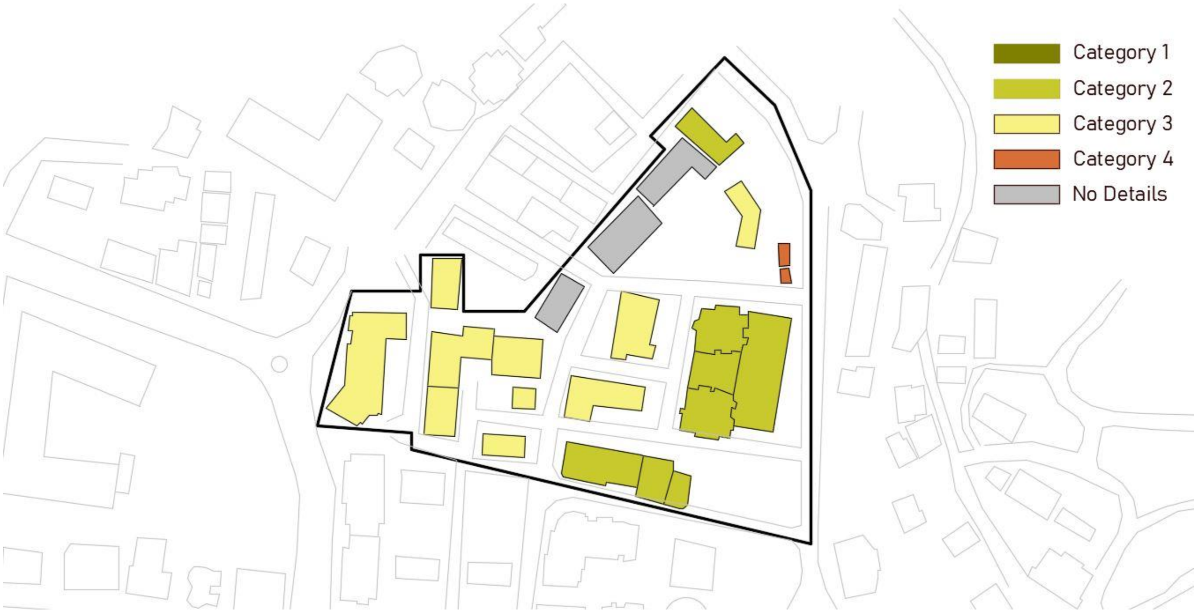


Figure 7.27 "Function" spatial distribution for the selected area in Lezhë

Figure 7.28 "Utilization" spatial distribution for the selected area in Lezhë

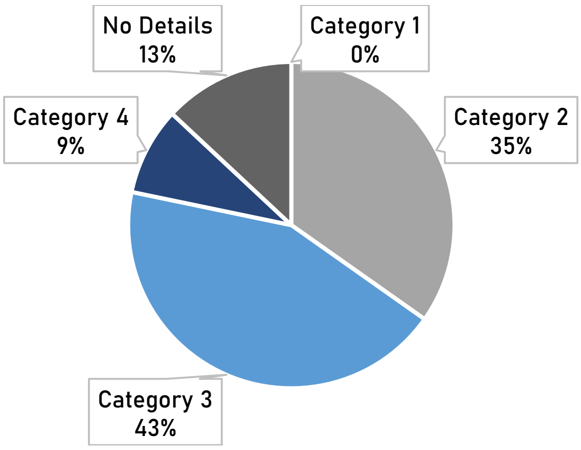


Figure 7.29 "Function" chart for the selected area in Lezhë

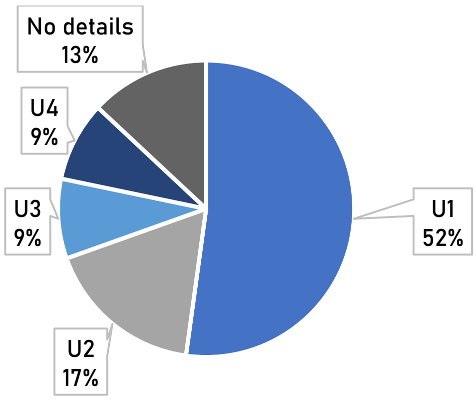


Figure 7.30 "Utilization" chart for the selected area in Lezhë

7.2.4 Local Scale analysis

Floor Space Index and Building Distance

Floor Space Index is calculated based on the building area (as a sum of the area of the total buildings) together with the site area. From the applied point of view polylines can be used to easily calculate the areas. Calculations of the area show that the total built area is 26894.4 m^2 while the area of the site is 23400m^2, thus resulting in a value of **1.15** for the FSI.

Regarding the building distances, most objects are located very close to one another, resulting in no clear spacing within one another. The main reason for the lack of such space is due to the height of the objects. For a conservative approach, to reflect the worst conditions from this point of view, for the entire area the clear space for each of the buildings is considered **0m**.

Network Density and Connectivity

The combination of network density with the connectivity showed that the studied area in overall has a good street network. In terms of the coverage, the value of SCR which is given in the proposed plans for the site is 15%, which standardized corresponds to a value of 0.27. The specific area may be considered as accessible since as shown in Fig. 7.31 there are 6 clear permeable points to access this area. In total there are 13 nodes and 23 links corresponding to a value of β of 1.76. Using the corresponding value function, the standardized value of β is 0, reflecting a very good situation from this point of view.

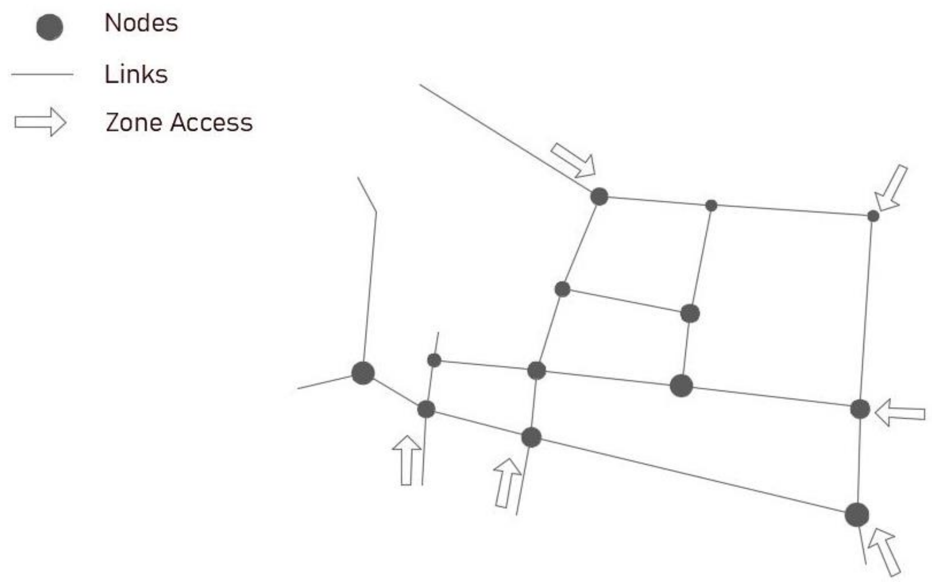


Figure 7.31 Street network diagram for the selected areas in Lezhë

Open Space Accessibility

Site visits and map analysis showed that within the range of the selected area there is no open space, besides some small parking lots that can partially serve as shelter area during the emergency phase. Therefore, it was decided that for this variable an analysis including a wider range ought to be done to highlight potential open spaces. Such analysis showed that around the area there are some small open spaces like parking lots and the stadium of the city. Considering that the area is quite accessible, as evidenced in the previous paragraph, the open space distance using simple polyline measures in Google Earth was considered to vary in the range of 500-700m, which is translated into a standardized value of 0.26

7.2.5 Risk Assessment

In the same way as with the previous case study risk has been calculated combining the data in two levels; small scale and local scale, using the weighted linear combination method. For the case of Lezhë there are relatively high levels of hazards due to the combination of the peak ground acceleration with the ground type. The corresponding standardized value of hazard is 0.42. Regarding the vulnerability and exposure variable, as shown by the summarized tables, the majority of buildings have high to moderate values of vulnerability (VE4 and VE3).

Such values are mainly due to the building age and typology since there is a lack of updated design codes and most of the buildings are design using old national codes and, in many cases, even without following specific standards since for many years Albania was characterized by informal settlements.

The combination of relative high hazard levels with a high and moderate vulnerability levels produced a risk level of R3 for the majority of the buildings in the selected area which based on table 6.42 consist in high risk. The summarized information of the real data together with the standardized values for each of the buildings is given in the corresponding appendices (see Appendix B). The output is given in the form of vulnerability and risk maps as shown below:

Figure 7.32 Vulnerability and Exposure levels for the selected area in Lezhë

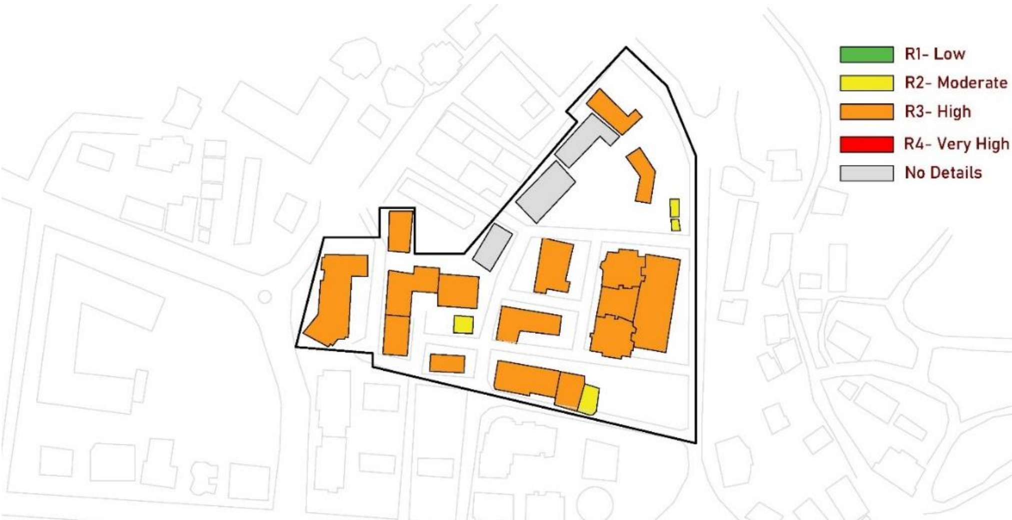


Figure 7.33 Risk levels for the selected area in Lezhë

8 Conclusions, Recommendations and Future Perspectives

The final chapter of the dissertation summarizes the research in the form of conclusions and recommendations together with further improvements. The conclusions are two folded; firstly, related to the theoretical framework and secondly to the methodology itself, emphasizing the role in the actual research in the field of Disaster Risk Reduction and Disaster Risk Management.

It is also specified that the methodology is oriented towards a number of stakeholders (as part of a holistic and inclusive process). The way these stakeholders including; the community, local and national authorities and experts, are integrated and can collaborate with one another with the aim of fostering DRR practice and policies is given with the help of a scheme reflecting a closed cycle.

8.1 Conclusions and Recommendations

In developing strategies for disaster risk reduction one of the main challenges has been the communication and dissemination of risk information. As concluded by (Gaillard & Mercer, 2012) the main problematics are related to the low levels of perception from the local community and authorities, together with lack of proper integration of a comprehensive risk information aiming to foster the collaboration between stakeholders. The inability for such communication among other factors represented gaps that needed to be analyzed in order to improve the efficiency of Disaster Risk Reduction (DRR) intervention and strategies. DRR has been considered as a process by the people for the people and thus eventual proposal of strategies needs to be developed focusing on local communities since it is directly affected by the disasters. This research focused on the possible ways to bridge the gaps in the form of knowledge, top-down and bottom-up approaches and the collaboration and operation of large array of stakeholders.

Urban planning together with its instruments is an important connecting nod between the community and relevant authorities in different operational levels from local to national and regional, for this reason the integration of risk information within planning instruments would definitely strengthen the link and foster the collaboration. Such processes are believed to improve urban resilience and create resilient cities with a focus on learning, responsiveness and capacity and resourcefulness.

Taking into considerations the demands and needs for an inclusive DRR, the research was oriented towards the proposal of an updated methodology that could integrate specific variables aimed at combining firstly the information at different scales (building and zone), and secondly information from different perspectives: engineering and planning. The main objective was that of generating an effective and essential information which is depicted spatially and would serve as an input for preliminary decision-making processes. Such processes could be in terms of interventions, fund allocations, additional mitigation measures within existing settlements and also predictions for future planned settlements taking into consideration the potential seismic risk due to the vulnerability levels from the intrinsic characteristic of such built systems.

The focus was such that beyond the core of the methodology, the result could be easily interpretable by the community with the objective of increasing the *perception of risk*, which often, especially in the case of rare events such as earthquakes is not present, thus reflecting a negligence not only from the local community but also from local authorities.

The constituting elements of risk; hazard, vulnerability and exposure were characterized based on a specific number of variables combined in a linear hierarchic scheme in the form of indices. Since there were numerous variables that could be integrated in the proposed methodology a selection procedure was necessary. The variables were selected based on three main criteria; complexity, information and importance. The first criterion was conceptualized such as to generate a methodology which would give preliminary risk values with a minimal complexity and improve the effectiveness in terms of time and integration. On the other hand, the second criterion was related to the possibility of eventual data collection for the selected variables and lastly, the third criterion corresponded to the selection of the variables that had a greater influence on the final value of risk, based on extensive literature research. A total of 14 variables were selected, 3 of which describe seismic action and the influence of local conditions (soil and topography), 6 variables describe the characteristics at a building scale and the final 5 variables are used to describe the characteristics of the surrounding urban environment. The data related to selected variables and final results corresponding with the values of vulnerability and risk were given in the form of spatial information using mapping processes to clearly show the spatial distribution of risk within the selected areas.

The two selected case study areas, represented different contexts in many aspects. The case of Guimarães in Portugal was a typical historical area having a great cultural and identity importance, characterized by old low-rise buildings and with a good performance in terms of urban configuration. On the other hand, the case of Lezhë in Albania represented a modern context with high rise buildings and a complex configuration. The opposite nature of this selected areas showed the adaptability of the proposed model. Such adaptability proved that even though the information is context specific the variables selected are such that ease the implementation and data collection. As expected, the vulnerability levels for these case studies had different sources, in the first case the structural typology and materials together with lack of clear spaces were the main factors. While for the second case, function and utilization levels reflected high level of exposure, combined with relatively poor urban configuration.

As aforementioned the main objective of the proposed methodology in this research was that of adding information and calculation models to spatial planning instruments, aiming at improving the strategies for Disaster Risk Reduction. The research showed that a multi-disciplinary approach imposes a multi-scale approach from the operational scale (the building) to the strategic scale (zone scale). A detailed analysis on a building scale would definitely give a complete information regarding the expected level of damages from a possible seismic event, but would lack in giving the relationship between the object itself and the surrounding urban environment. Such aspect is of a greater importance not only during the emergency phase of a disaster, but also during a later recovery phase, since the analysis at such scale generates possible alternatives accelerating such process. The selection of indices to evaluate risk highlighted a facilitated the entire analysis. It can be concluded that such standardized process would facilitate the process of data integration and improve the level of data understanding from a decision-making point of view. In addition, such analysis showed that variables of different natures can be combined easily and is possible to judge about the importance of each variable in relation to the other.

In terms of the main research question regarding the effectiveness of integrating risk knowledge within planning instruments, it can be concluded that a multi-scale approach is necessary in switching towards inclusive DRR processes since it gives the possibility of combining different **form of knowledge** context specific with generalized scientific data. It also fosters a **top-down and bottom-up approach** because the data collection and elaboration is context specific giving an output to local and national authorities, while on the other hand such approaches require an understanding of the event at a regional and national scale, implying the need for coordination and information in these levels. Such approach imposes also a **vast majority of stakeholders**. On one hand there is the local community, which is directly affected from such events and on the other hand there are local and national institutions. In addition, social and physical scientists are the other important actors. The proposed methodology for risk evaluation represents a tool which can be easily adapted and improved by these scientists by adding the necessary information and variables and re-interpreting the hierarchy system. The scientists and specialists in collaboration with local institutions can foster the adaptive capacities of the local community since the results can be translated in interventions like prioritization, evacuation routes, faster responses and better dissemination of information.

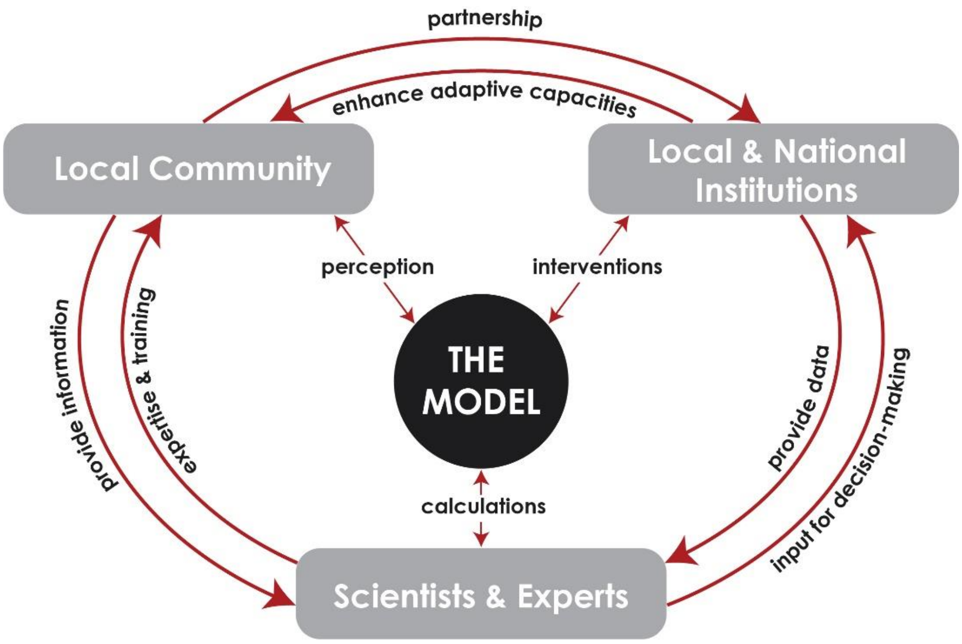


Figure 8.1 Integration of the stakeholders

It is recommended that the output of the research after "filtering" in the national and local institutions can be used to target local community with the aforementioned dissemination objective. By creating a clear, open-source and easy structure the community is not marginalized in terms of information and means of protection. The transmission of the information in non-technical terms for the local community can be done by a combination of specific training and teaching processes, together with alternative ways of disseminating the risk knowledge.

The overcoming of "non-technical" information challenge can be done using mapping processes as visualization of the data spatially not only depicts the distribution of risk, but also impacts the viewer perception. Which is hardly feasible to be done in other technical ways using graphs, tables, charts or any other potential means, since they require a specific knowledge in fields of scientific and non-scientific subjects. It can also be recommended that since a risk analysis is always time dependent and dynamic a time variable can be integrated to show growing trends and developments.

8.2 Future perspectives

Following the main objectives of the research, as specified in the previous paragraphs, it is believed that such research could lead to further development and improvement. Based on the complexity of the problem, there is the possibility for a better specification and accuracy of information. As such, the proposed variables have a horizontal linear relationship in the form of a hierarchical structure which can be seen as a two-dimensional representation of the problem. A transition to a third dimension can be attempted with the aim of linking the variables so that the interdependencies of critical infrastructures within an urban system are also considered. This can be achieved by using advanced probabilistic graphical models such as Bayesian networks.

The selection of the variables is such that it allows the study of the problem not only on a zone scale, but also on a city scale, serving as a basis for the development of a simple user-friendly instrument that aims to communicate current and future scenario-based risk levels. Future improvements might imply the integration of new variables to take into account other aspects of risk assessment, for instance social components or environmental impacts to switch into a holistic approach. From this point of view, the proposed model is flexible allowing for integration of new variables or new hierarchical levels.

The tool in the form of an application and software can be used by specialists to assess and map the risk based on appropriate research, by the local institutions to define interventions and by local communities to raise awareness and risk perception. A potential outcome can also be in terms of more technical and legal aspects. For instance, the application of the methodology and the obtained results can be attached in the form of a technical datasheet for each owner to have, and this can be done for existing buildings and new ones. In this way, the owners have complete information about risk and the local institutions also would have an updated database.

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9 Appendix A: Survey for the determination of the relative importance of the variables contributing in the Seismic Risk

Weight Assignment for Seismic Risk Evaluation

The survey is used to determine the **relative importance** of several variables included in a semi-quantitative methodology generated to evaluate seismic risk in a local scale as part of a doctoral research

1. What is your field of expertise?

   ☐ Civil Engineering

   ☐ Urban Planning

   ☐ Architecture

   ☐ Other: ___________________________

PART 2- RELATIVE IMPORTANCE OF THE VARIABLES

The technique used for the weighting is the Analytic Hierarchy Process, therefore the qualitative evaluation is based on the proposed scale by this technique

2. In terms of contribution to the level of risk, based on your judgement local soil conditions with regard to topography is:
   - Equally Important
   - Slightly Important
   - Moderately important
   - Strongly Important
   - Extremely Important
   - Other: ___________________________________

3. In terms of contribution to the level of risk, based on your judgement building age with regard to number of storeys (building height) is:
   - Equally Important
   - Slightly Important
   - Moderately important
   - Strongly Important
   - Extremely Important
   - Other: ___________________________________

4. In terms of contribution to the level of risk, based on your judgement building (structural) typology with regard to the state of conservation is:
   - ○ Equally Important
   - ○ Slightly Important
   - ○ Moderately important
   - ○ Strongly Important
   - ○ Extremely Important
   - ○ Other: ______________________________

5. In terms of contribution to the level of risk, based on your judgement function with regard to utilization is:

   Function relates to the importance of the building unit (residential, commercial are some examples of building function). Utilization is used to express the level of exposure in terms of ***number of people*** *in the building and the* ***time of daily usage*** *of the building*

   - ○ Equally Important
   - ○ Slightly Important
   - ○ Moderately important
   - ○ Strongly Important
   - ○ Extremely Important
   - ○ Other: ______________________________

6. In terms of contribution to the level of risk, based on your judgement FSI with regard to building distance is:

   FSI (Floor Space Index) representing the ratio of the total floor area of the building with the area of the plot. Building distance representing the clear space between buildings to avoid domino effects

   - ○ Equally Important
   - ○ Slightly Important
   - ○ Moderately important

- Strongly Important
- Extremely Important
- Other: ____

7. In terms of contribution to the level of risk, based on your judgement street connectivity with regard to street coverage is:
    - Equally Important
    - Slightly Important
    - Moderately important
    - Strongly Important
    - Extremely Important
    - Other: ____

8. Based on the relative importance, the appropriate order of the following variables would be

    Physical density represents the density of the buildings in a specified area taking into account FSI and building distance

    - Physical Density, Street Network, Open Space
    - Physical Density, Open Space, Street Network
    - Street Network, Physical Density, Open Space
    - Street Network, Open Space, Physical Density
    - Open Space, Physical Density, Street Network,
    - Open Space, Street Network, Physical Density

9. From 1 (same importance) to 9 (extremely important) the importance of structural characteristics in comparison with the functionality is

Functionality combines function with utilization (see above)

1	2	3	4	5	6	7	8	9

10. From 1 (same importance) to 9 (extremely important) the importance of structural characteristics in comparison with the external elements is

External elements represent the characteristics of the surrounding environment in terms of street network, physical density and open space accessibility

1	2	3	4	5	6	7	8	9

11. From 1 (same importance) to 9 (extremely important) the importance of structural characteristics in comparison with the building characteristics is

building characteristics are used to characterize buildings mainly in terms of their age and number of storeys

1	2	3	4	5	6	7	8	9

12. From 1 (same importance) to 9 (extremely important) the importance of functionality in comparison with the external elements is

1	2	3	4	5	6	7	8	9

13. From 1 (same importance) to 9 (extremely important) the importance of functionality in comparison with the building characteristics is

1	2	3	4	5	6	7	8	9

14. From 1 (same importance) to 9 (extremely important) the importance of external elements in comparison with the building characteristics is

1	2	3	4	5	6	7	8	9

15. If different opinion regarding the relative importance of the variables (using the same scale from 1-9), please specify below

10 Appendix B: Summarized Tables of the real data, standardized data and risk categorization

B.1 Real data for each building unit- The case of Guimarães, Portugal

Building ID	Topography	Ground Type	PGA	Number of storeys	Building age	Building typology	State of Conservation	Function	Utilization	FSI	Building Distance	SCR	β	Open Space Distance
	(o)	(-)	(g)	(-)	year	(-)	(-)	(-)	(-)	(-)	(m)	(%)	(-)	(m)
Z3-A-01	10.8	A	0.12	2	<1979	Stone	Good	Category 3	U4	0.92	No clear distance	16.36	1.87	<200
Z3-A-02	10.8	A	0.12	2	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-03	10.8	A	0.12	2	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-04	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-05	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-06	10.8	A	0.12	3	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-07	10.8	A	0.12	3	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-08	10.8	A	0.12	3	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-09	10.8	A	0.12	3	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-10	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-11	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-A-12	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-A-13	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-A-14	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-15	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-16	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-A-17	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-18	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-19	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-20	10.8	A	0.12	2	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-21	10.8	A	0.12	2	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-A-22	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-A-23	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-01	10.8	A	0.12	4	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200

Z3-B-02	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-03	10.8	A	0.12	2	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-04	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-B-05	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-B-06	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-B-07	10.8	A	0.12	4	<1979	Stone	Very Good	Category 4	U4	0.92	No clear distance	16.36	1.87	<200
Z3-B-08	10.8	A	0.12	4	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-09	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-10	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-11	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-12	10.8	A	0.12	3	<1979	Stone	Poor	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-B-13	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-B-14	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-B-15	10.8	A	0.12	3	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-B-16	10.8	A	0.12	3	<1979	Stone	Good	Category 4	U4	0.92	No clear distance	16.36	1.87	<200
Z3-B-17	10.8	A	0.12	4	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-B-18	10.8	A	0.12	3	<1979	Stone	Very Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-B-19	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-20	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-21	10.8	A	0.12	4	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-22	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-B-23	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-B-24	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-B-25	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-C-01	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-C-02	10.8	A	0.12	3	<1979	Stone	Good	Category 4	U4	0.92	No clear distance	16.36	1.87	<200
Z3-C-03	10.8	A	0.12	3	<1979	Stone	Good	Category 3	U2	0.92	No clear distance	16.36	1.87	<200
Z3-C-04	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U1	0.92	No clear distance	16.36	1.87	<200

Z3-D-01	10.8	A	0.12	2	<1979	Stone	Very Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200
Z3-D-02	10.8	A	0.12	2	<1979	Stone	Very Good	Category 1	U3	0.92	No clear distance	16.36	1.87	<200
Z3-D-03	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-D-04	10.8	A	0.12	3	<1979	Stone	Very Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-D-05	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-D-06	10.8	A	0.12	3	<1979	Stone	Good	Category 4	U4	0.92	No clear distance	16.36	1.87	<200
Z3-D-07	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-E-01	10.8	A	0.12	3	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-E-02	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-E-03	10.8	A	0.12	3	<1979	Stone	Good	Category 4	U4	0.92	No clear distance	16.36	1.87	<200
Z3-E-04	10.8	A	0.12	3	<1979	Stone	Very Poor	Category 4	U4	0.92	No clear distance	16.36	1.87	<200
Z3-E-05	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-E-06	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-E-07	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-E-08	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-E-09	10.8	A	0.12	No details	No details	No details	No details	No details	No details	0.92	No details	16.36	1.87	<200
Z3-E-10	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-E-11	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U2	0.92	No clear distance	16.36	1.87	<200
Z3-E-12	10.8	A	0.12	4	<1979	Stone	Good	Category 2	U3	0.92	No clear distance	16.36	1.87	<200

B.2 Standardized values and risk categorization for each building unit- The case of Guimarães, Portugal

				VULNERABILITY AND EXPOSURE (TOTAL)											RISK	RISK Class	Vulnera-bility	Vulnera-bility Class
	HAZARD			VULNERABILITY AND EXPOSURE (BUILDING SCALE)						VULNERABILITY AND EXPOSURE (EXTERNAL)								
	Topography	Ground Type	PGA	Number of storeys	Building age	Building typology	State of Conservation	Function	Utilization	FSI	Building Distance	SCR	β	Open Space Distance				
Z3-A-01	0	0	0.12	0	1	1	0.25	0.56	0	0	1	0.27	0	0	0.34	R2	0.62	VE4
Z3-A-02	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-A-03	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-A-04	0	0	0.12	0.33	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.71	VE4
Z3-A-05	0	0	0.12	0	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-A-06	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-A-07	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-A-08	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-A-09	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-A-10	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-A-11	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-A-12	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-A-13	0	0	0.12	0	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-A-14	0	0	0.12	0	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.71	VE4
Z3-A-15	0	0	0.12	0	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.71	VE4
Z3-A-16	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-A-17	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-A-18	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-A-19	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-A-20	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-A-21	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-A-22	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	R4	-	-
Z3-A-23	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-B-01	0	0	0.12	0.33	1	1	0	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.7	VE4
Z3-B-02	0	0	0.12	0.33	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.72	VE4
Z3-B-03	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.69	VE4
Z3-B-04	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-B-05	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-B-06	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-B-07	0	0	0.12	0.33	1	1	0	0	0	0	1	0.27	0	0	0.22	R2	0.4	VE2
Z3-B-08	0	0	0.12	0.33	1	1	0	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.7	VE4
Z3-B-09	0	0	0.12	0.33	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.72	VE4
Z3-B-10	0	0	0.12	0.33	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.72	VE4
Z3-B-11	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.37	R2	0.69	VE4
Z3-B-12	0	0	0.12	0	1	1	0.76	0.85	0.94	0	1	0.27	0	0	0.38	R2	0.7	VE4
Z3-B-13	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-B-14	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-B-15	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-B-16	0	0	0.12	0	1	1	0.25	0	0	0	1	0.27	0	0	0.23	R2	0.41	VE3

Z3-B-17	0	0	0.12	0.33	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-B-18	0	0	0.12	0	1	1	0	0.56	0.94	0	1	0.27	0	0	0.35	R2	0.65	VE4
Z3-B-19	0	0	0.12	0	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.71	VE4
Z3-B-20	0	0	0.12	0.33	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.72	VE4
Z3-B-21	0	0	0.12	0.33	1	1	0	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.7	VE4
Z3-B-22	0	0	0.12	0.33	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-B-23	0	0	0.12	0	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.71	VE4
Z3-B-24	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-B-25	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-C-01	0	0	0.12	0	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-C-02	0	0	0.12	0	1	1	0.25	1	0	0	1	0.27	0	0	0.24	R2	0.4	VE2
Z3-C-03	0	0	0.12	0	1	1	0.25	0.56	0.94	0	1	0.27	0	0	0.36	R2	0.67	VE4
Z3-C-04	0	0	0.12	0	1	1	0	0.85	1	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-D-01	0	0	0.12	0	1	1	0	0.85	0.73	0	1	0.27	0	0	0.38	R2	0.7	VE4
Z3-D-02	0	0	0.12	0	1	1	0	1	0.73	0	1	0.27	0	0	0.39	R2	0.73	VE4
Z3-D-03	0	0	0.12	0	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-D-04	0	0	0.12	0	1	1	0	0.85	0.94	0	1	0.27	0	0	0.39	R2	0.72	VE4
Z3-D-05	0	0	0.12	0.33	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-D-06	0	0	0.12	0	1	1	0.25	0	0	0	1	0.27	0	0	0.24	R2	0.4	VE2
Z3-D-07	0	0	0.12	0	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-E-01	0	0	0.12	0	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-E-02	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-E-03	0	0	0.12	0	1	1	0.25	0	0	0	1	0.27	0	0	0.24	R2	0.4	VE2
Z3-E-04	0	0	0.12	0	1	1	1	0	0	0	1	0.27	0	0	0.26	R2	0.46	VE3
Z3-E-05	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-E-06	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-E-07	0	0	0.12	0.33	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-E-08	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-E-09	0	0	0.12	No details	No details	No details	No details	No details	No details	0	1	0.27	0	0	-	-	-	-
Z3-E-10	0	0	0.12	0.33	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-E-11	0	0	0.12	0.33	1	1	0.25	0.85	0.94	0	1	0.27	0	0	0.4	R2	0.74	VE4
Z3-E-12	0	0	0.12	0.33	1	1	0.25	0.85	0.73	0	1	0.27	0	0	0.39	R2	0.72	VE4

B.3 Real data for each building unit- The case of Lezhë, Albania

Building ID	Topography	Ground Type	PGA	Number of storeys	Building age	Building typology	State of Conservation	Function	Utilization	FSI	Building Distance	SCR	β	Open Space Distance
	(o)	(-)	(g)	(-)	year	(-)	(-)	(-)	(-)	(-)	(m)	(%)	(-)	(m)
LE-01	4	C	0.338	10	1990-2010	RC1	Good	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-02	4	C	0.338	6	1990-2010	RC1	Good	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-03	4	C	0.338	7	1990-2010	RC1	Good	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-04	4	C	0.338	7	1990-2010	RC1	Good	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-05	4	C	0.338	3	>2010	RC2	Very Good	Category 3	U2	1.15	No clear distance	15	1.76	500-700
LE-06	4	C	0.338	5	1979-1990	M2	Poor	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-07	4	C	0.338	4	1979-1990	M2	Very Good	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-08	4	C	0.338	No details	No details	No details	No details	No details	No details	No details	No details	15	1.76	500-700
LE-09	4	C	0.338	5	1979-1990	M2	Very Poor	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-10	4	C	0.338	8	>2010	RC2	Very Good	Category 2	U1	1.15	No clear distance	15	1.76	500-700
LE-11	4	C	0.338	7	>2010	RC2	Very Good	Category 2	U1	1.15	No clear distance	15	1.76	500-700
LE-12	4	C	0.338	3	>2010	RC2	Very Good	Category 2	U2	1.15	No clear distance	15	1.76	500-700
LE-13	4	C	0.338	5	1979-1990	M2	Good	Category 3	U1	1.15	No clear distance	15	1.76	500-700
LE-14	4	C	0.338	No details	No details	No details	No details	No details	No details	No details	No details	15	1.76	500-700
LE-15	4	C	0.338	No details	No details	No details	No details	No details	No details	No details	No details	15	1.76	500-700
LE-16	4	C	0.338	3	1990-2010	RC1	Good	Category 2	U3	1.15	No clear distance	15	1.76	500-700
LE-17	4	C	0.338	9	1990-2010	RC1	Good	Category 2	U1	1.15	No clear distance	15	1.76	500-700
LE-18	4	C	0.338	2	1990-2010	RC1	Good	Category 2	U3	1.15	No clear distance	15	1.76	500-700
LE-19	4	C	0.338	9	1990-2010	RC1	Good	Category 2	U1	1.15	No clear distance	15	1.76	500-700
LE-20	4	C	0.338	1	1990-2010	RC1	Good	Category 2	U2	1.15	No clear distance	15	1.76	500-700
LE-21	4	C	0.338	4	1979-1990	M2	Poor	Category 3	U2	1.15	No clear distance	15	1.76	500-700
LE-22	4	C	0.338	1	1990-2010	M2	Poor	Category 4	U4	1.15	No clear distance	15	1.76	500-700
LE-23	4	C	0.338	1	1990-2010	M2	Poor	Category 4	U4	1.15	No clear distance	15	1.76	500-700

B.4 Standardized values and risk categorization for each building unit- The case of Lezhë, Albania

				VULNERABILITY AND EXPOSURE (TOTAL)											RISK	RISK Class	Vulnera-bility	Vulnera-bility Class
	HAZARD			VULNERABILITY AND EXPOSURE (BUILDING SCALE)						VULNERABILITY AND EXPOSURE (EXTERNAL)								
	Topography	Ground Type	PGA	Number of storeys	Building age	Building typology	State of Conservation	Function	Utilization	FSI	Building Distance	SCR	β	Open Space Distance				
LE-01	0	0.55	0.43	0.66	0.48	0.8	0.25	0.56	1	0.26	1	0.27	0	0.26	0.53	R3	0.62	VE4
LE-02	0	0.55	0.43	0.33	0.48	0.8	0.25	0.56	1	0.26	1	0.27	0	0.26	0.53	R3	0.61	VE4
LE-03	0	0.55	0.43	0.33	0.48	0.8	0.25	0.56	1	0.26	1	0.27	0	0.26	0.53	R3	0.61	VE4
LE-04	0	0.55	0.43	0.33	0.48	0.8	0.25	0.56	1	0.26	1	0.27	0	0.26	0.53	R3	0.61	VE4
LE-05	0	0.55	0.43	0	0	0	0	0.56	0.94	0.26	1	0.27	0	0.26	0.37	R2	0.3	VE2
LE-06	0	0.55	0.43	0.33	0.79	0.6	0.76	0.56	1	0.26	1	0.27	0	0.26	0.52	R3	0.63	VE4
LE-07	0	0.55	0.43	0	1	1	0.25	0.56	0.94	0.26	1	0.27	0	0.26	0.52	R3	0.61	VE4
LE-08	0	0.55	0.43	No details	No details	No details	No details	No details	No details	0.26	1	0.27	0	0.26	-	-	-	-
LE-09	0	0.55	0.43	0.33	0.79	0.6	1	0.56	1	0.26	1	0.27	0	0.26	0.53	R3	0.61	VE4
LE-10	0	0.55	0.43	0.66	0	0	0	0.85	1	0.26	1	0.27	0	0.26	0.42	R3	0.39	VE2
LE-11	0	0.55	0.43	0.33	0	0	0	0.85	1	0.26	1	0.27	0	0.26	0.41	R3	0.38	VE2
LE-12	0	0.55	0.43	0	0	0	0	0.85	0.94	0.26	1	0.27	0	0.26	0.4	R2	0.37	VE2
LE-13	0	0.55	0.43	0.33	0.79	0.6	0.25	0.56	1	0.26	1	0.27	0	0.26	0.5	R3	0.56	VE3
LE-14	0	0.55	0.43	No details	No details	No details	No details	No details	No details	0.26	1	0.27	0	0.26	-	-	-	-
LE-15	0	0.55	0.43	No details	No details	No details	No details	No details	No details	0.26	1	0.27	0	0.26	-	-	-	-
LE-16	0	0.55	0.43	0	0.48	0.8	0.25	0.85	0.73	0.26	1	0.27	0	0.26	0.54	R3	0.64	VE4
LE-17	0	0.55	0.43	0.66	0.48	0.8	0.25	0.85	1	0.26	1	0.27	0	0.26	0.57	R3	0.69	VE4
LE-18	0	0.55	0.43	0	0.48	0.8	0.25	0.85	0.73	0.26	1	0.27	0	0.26	0.54	R3	0.64	VE4
LE-19	0	0.55	0.43	0.66	0.48	0.8	0.25	0.56	1	0.26	1	0.27	0	0.26	0.53	R3	0.62	VE4
LE-20	0	0.55	0.43	0	0.48	0.8	0.25	0.85	0.94	0.26	1	0.27	0	0.26	0.56	R3	0.67	VE4
LE-21	0	0.55	0.43	0.33	0.79	0.6	0.76	0.56	0.94	0.26	1	0.27	0	0.26	0.52	R3	0.59	VE3
LE-22	0	0.55	0.43	0	0.48	0.6	0.76	0	0	0.26	1	0.27	0	0.26	0.38	R2	0.31	VE2
LE-23	0	0.55	0.43	0	0.48	0.6	0.76	0	0	0.26	1	0.27	0	0.26	0.38	R2	0.31	VE2